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Riparian buffer strips in the Bear Creek watershed

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by

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To my husband,

Frédéric Bercovici

"More than any other people, farmers work directly with the natural systems of the earth. They're on the cutting edge. They can become the thoughtful leaders in the protection of earth's resources - which they work with every day and recognize as limited and fragile.
Nothing is more complex than farming, or more variable from place to place. Farmers have the world as a dependent as they themselves are dependent on the preservation of good soil and good water."

(Iowa State University Extension, 1993)

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DEFINITIONS

a) A *watershed* is "a topographically delineated area that is drained by a stream system. The watershed is a hydrological unit that has been described and used both as a physical-biological unit and as a sociopolitical unit for planning and implementing resource management activities" (Dixon and Easter, 1986).

b) *Water quality* is a relative concept and is influenced by a number of natural and man-made factors. Water pollution can be defined in many ways in terms of various measures of quality. The basic definition is the introduction of concentrations of a particular substance into water for a period of time long enough to cause harmful effects, or, more generally, a condition that makes water unusable for a particular purpose. The term water quality means those characteristics (chemical, physical and biological) that are distinctive to a particular body of water that is used for drinking, manufacturing, agriculture, recreation or management of wildlife (Dzurik, 1990; Ward and Talbot, 1988).

c) A *riparian vegetated buffer* is an area of trees and/or other vegetation located in areas adjacent to and upgradient from water bodies. The function of this strip of vegetation is to intercept surface runoff, wastewater, surface and groundwater flows from upland sources for the purpose of removing sediment, nutrient pollutants and other organic pollutants before they can enter surface waters and groundwater recharge areas (Dzurik, 1990; Lowrance et al., 1984a; Lowrance et al., 1984b; Welsch, 1991).

d) *Stream order* is a system of stream classification. Perennial streams are the basis for the classification of stream orders. According to Horton-

Strahler's system, headwater streams which receive no tributaries are called first-order streams. When two first-order streams unite, a second order stream is formed. Two second-order streams unite to form a third-order stream and so on. Where two streams of different order join, the combined stream retains the order of the highest order stream contributing to it.

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CHAPTER 1. INTRODUCTION

In the course of time, civilization has adapted to the constant pattern by which the planet recycles water between the oceans evaporation, the land distribution and storage, and the final return to the seas. Unfortunately, along with the changeover to industrialization and the progress of technologies, a dramatic modification in our relationship to the earth has occurred. It has caused tremendous damage to the global water system, and is responsible for several threats.

The functioning of the planet depends on interrelations between different systems. Global warming of the atmosphere, for instance, is responsible for the rapid warming of the polar regions, which in turn has the potential to modify the ocean currents and the climate pattern. Another consequence of global warming is the rising level of the oceans because higher temperatures cause glaciers to melt, which produces an increased volume. The third menace to the planet water system is massive deforestation, which directly affects the hydrological cycle and causes droughts and erosion. The fourth threat to the earth water resources is the worldwide contamination with chemical pollutants produced by our industries. These include oil spills, toxic metals ... but mostly compounds created in order to improve agricultural productivity: fertilizers, herbicides, insecticides. Still, sediment, caused by erosion, is the largest pollutant of water resources (Armstrong et al., 1990; Crosson, 1985; Hamilton and Pearce, 1990).

The water system of agricultural soils, like the one of the atmosphere, does have the ability to clean itself. However, mismanagement can lead to an overloading of this filtering action. It is then impossible to get rid of all the pollutants. The pollution of the oceans, rivers, lakes and creeks is thus a real threat. As a matter of fact, it has been growing continuously, making the situation even worse. In different countries throughout the world, agencies have become alarmed and have begun to work to clean up their water. This awareness is really needed if the goal is to protect the water resources of our planet. Albert Gore (1992) actually put this into words: "We need to lasso our common sense. The lakes and rivers sustain us; they flow through the veins of the earth and into our own. But we must take care to let them flow back out as pure as they came, not poison and waste them without thought for the future."

This goal cannot be achieved without bringing changes in our current "destroying" relationship to the earth resources. Until the industrial revolution and the rapid progress gained by science and technology, farming was, for the most, a respectful cultivation of the land with multicrop rotation including fallow, and very little input of "supplements", except for animal manure. Now, agricultural practices have become more like industrial practices. Increased productivity has been the driving force. Livestock production has led to higher animal concentrations. Along with common monoculture, massive use of chemicals has become an essential component of farming. Agriculture has even reached the point where a new chemical seems to be the answer to any arising problem. However, there is awareness of the importance of chemical use. Technological improvements have mitigated the impact of pesticides on the environment: along with shorter half lives, the new compounds have become more target specific and effective in lower concentrations (Welsch, 1991). In addition, biological controls that occur in nature have been refined. Research is also being conducted on how to reduce fertilizer inputs (Burt, 1987; OCDE, 1986). The application of nitrogen in the fall, for example, has been tested (Iowa State University Extension, 1993). Nevertheless, the current system locks farmers into pesticide and fertilizer cycles (Hightower, 1989). The land itself becomes less and less capable of supporting plant growth without increasing amounts of fertilization. This farming situation describes what is typically found in North America, and especially in the Midwest. Iowa, in particular, is a good example of that region because it is famous worldwide for being the number one agricultural American state, with its bountiful harvest of crops and livestock.

The Iowa landscape, like the Midwestern one, is a mosaic of crop and pasture lands. Where they stand now is what formerly was prairies, wetlands and forests. The Bear Creek watershed (p.viii) in Iowa is located in the most intensively cultivated region of the state, and therefore represents an example of the impact of intensive agricultural land use on a watershed. These conditions prompted conducting research in the Bear Creek watershed to determine the relationship between water quality degradation and farming practices. The long-term purpose of the research activity is to be able to recommend different agricultural management strategies for the watershed, that would sustain environmental resources, as well as preserve the farmers' returns.

In this field of defining sound agricultural practices, the focus of this study was to determine which areas along the creek are vulnerable to nonpoint source pollution (NPS) (sedimentation and chemical pollution), in order to identify where riparian buffer strips may be most useful. One aspect of the effectiveness of these zones on reducing NPS pollution, their width, also was examined. It was important to address the different possibilities of vegetative cover on the buffer strips too. Balancing the effectiveness of such hypothetical changes in management was important because having different arguments will help make farmers of the Bear Creek watershed aware that long-term agricultural sustainability, that is to say different management practices, is needed if we want to safeguard soils, groundwater, surface water and other natural resources.

CHAPTER 2. LITERATURE REVIEW

We all take water so much for granted that it is sometimes difficult to realize how vital it is to our existence (Balchin, 1991). People need water for a variety of uses: domestic purposes, agriculture, industrial purposes, power, removal of waste, transportation and recreation.

With the pressure of growing populations in the world, and rising standards of living, water becomes more and more needed and used. This increased demand has raised the awareness of how rare and fragile the water supply is, and how much it needs to be protected (Malandain, 1991).

At the international level, water resources issues are becoming an increasing concern (Dzurik, 1990). For example, the Worldwatch Institute has reported that worldwide trends of overuse, excessive withdrawals of surface and groundwater, and mismanagement of water resources threaten surface water quality and groundwater supplies all over the planet (Postel, 1985). The study cited the depletion of the Ogallala Aquifer in the west central United States as an example of mismanagement. It also suggested that shortages impacting food production and economies around the world could occur, and that governments are mostly ignoring water problems.

While trying to assess the adequacy of water supplies for the future, it has become clear in the last two decades that water quality (p. viii) is an important matter (Dzurik, 1990; Frederick, 1984). Through the media, the seriousness of water problems due to pollution from agriculture, industries, urban wastes and sewage has been emphasized (Konrad et al., 1986; Malandain and Tavernier, 1991). It seems as if the number of reports of bacteria, nitrates, synthetic chemicals, trace metals and other pollutants in water are constantly on the rise (Frederick, 1984; Knox and Moody, 1991). The general public has become very much concerned with the presence of agricultural chemicals in groundwater, because of the potential risk to human health associated with these chemicals in drinking water. Research has shown that lakes, rivers, streams and groundwater aquifers have some ability to clean themselves (Frederick, 1984; Ward, 1988). So long as pollution inputs are not exceeding these capabilities, pollution is not a major problem. But in many areas, these natural properties have been greatly overridden by the quantity and the toxicity of the pollutants introduced intentionally or not. The issue has thus resulted in considerable attention in the world, and in the United States, from a large number of various professions, including engineering, law, economics, geography, geology, regional planning and biology among others (Dzurik, 1990). Resource managers around the world have especially focused on watersheds (Dixon and Easter, 1986; Novotny, 1991), and have worked on developing watershed management plans (Applegate et al., 1986; Davenport et al., 1988; Hunt et al., 1988; Konrad et al., 1986). More and more research, carried on in Italy, Germany, Hungary, Philippines, India, Japan, New Zealand etc. and in the United States, has been warning about the deterioration of water quality in drainage basins.

The interest has developed because inadequate land use practices can lead to increased soil erosion and chemical pollution. In particular, the consideration of the interrelations between land use and water resources (surface water and groundwater) has become important (Dzurik, 1990).

Recently, attention has been drawn to the potential impacts of agricultural practices on water quality (National Research Council Committee on Conservation Needs and Opportunities, 1986), and the links between agriculture and water quality have become obvious (Braden and Uchtmann, 1985). Agriculture has many environmental impacts that extend beyond the farm boundary: it is in fact the most widespread human activity that affects surface and groundwater quality. The reason for that is because agriculture is a major source of water-borne pollutants (Felsot, 1988; Knox and Moody, 1991; Lant, 1989). The 1985 America's Clean Water assessment of the relative portion of waters impacted by various categories of pollution clearly showed that agriculture is the major contributor, responsible for 64% of the pollution of rivers and 57% of the pollution of lakes (Welsch, 1991).

Sources of water pollution are usually classified as either point or nonpoint (Konrad et al., 1986). Nonpoint sources are dispersed activities on land generating pollutants that are carried to lakes, streams or groundwater through runoff water. Nonpoint sources are hard to determine and result in chronic degradation of water quality, affecting surface waters (lakes, streams, estuaries) and groundwater supplies. Agriculture is a nonpoint source (NPS) of pollution. Sixty-eight percent of all U.S. river basins are affected by agricultural NPS pollutants (Lant, 1989). According to Konrad et al. (1986), Iowa is an area of great potential for rural NPS pollution in the U.S. It also has more than half of the nation's total river miles polluted by pesticides (Texas Agricultural Experiment Station, 1992).

Cropland erosion is the major erosion problem in the U.S. (Crosson, 1985). It can be caused by wind, water or livestock grazing (Blackburn et al., 1982). The process is that soil particles are detached from cropland and transported to waterways through runoff water (Crutchfield, 1988). About 60% of the eroded soil leaving the agricultural fields settles out of the runoff before it reaches a stream or another water body. Little is known about the fate of this portion of soil, and some of its consequences may not even be negative. For example, if this soil is deposited in an area where soil fertility is low, productivity may be enhanced. However, there appears to be a consensus that the major consequence of the deposited soil is negative. Suspended sediment does occur naturally in water bodies. But when practices on watershed soils result in an increased delivery of soil particles to water, streams become overloaded with suspended sediment. This excess of sediment clouds the water and silts up the water body.

One consequence is the blocking of sunlight penetration, which hinders the growth and reproduction of aquatic plants. Sedimentation at the bottom of streams interferes with the feeding and reproduction of fish and aquatic insects, which impacts the whole stream food chain (Crutchfield, 1988; Welsch, 1991). Of all NPS pollutants, sediment is considered to be the most important diffuse source of water quality degradation (Konrad et al., 1986; Ward and Talbot, 1988). In the U.S., the largest portion of sediment which enters surface waters comes from cropland erosion and averages 4 billion tons annually, with 240 million tons annually in Iowa. According to Soltner (1992), areas in the US that are the most affected by sedimentation are those associated with the production of row crops such as corn and soybeans in the Midwest.

Sediment can also carry attached chemicals from cropland such as phosphorus (P), nitrogen (N) or pesticides to surface waters (Crutchfield, 1988). Agrichemicals used in watersheds represent a great source of toxic substances for groundwater as well (Bashkin, 1989). For example, a 1988 statewide survey of 686 wells in Iowa indicated that 18% contained N concentrations higher than the safe drinking water standards (Iowa State University Extension, 1993). Chemicals are of concern to water quality for numerous reasons (Dzurik, 1990). They can cause eutrophication of water bodies, excess N and P enhancing algal growth thus depleting water oxygen and killing fish. The application of fertilizers (containing N and P) and pesticides (herbicides, fungicides and insecticides) to crops and pastures in excess of the amounts taken up by plants produces a buildup in the soil. Chemicals can then leach down through the soil and can contaminate groundwater supplies. Furthermore, irrigation increases losses of nutrients through leaching (Ward and Talbot, 1988). Because the use of synthetic fertilizers continues to be substantial, having increased in the past 50 years, the runoff of nutrients to waterways can be expected to remain a major water quality problem for some time. Moreover, Hallberg et al. (1985) affirm that pesticide use in agriculture is on the rise in Iowa.

Besides the impairment of water quality associated with runoff and chemical use, the other major agricultural pollutant is organic loading from animal feedlots. This organic material is an important source of N and P for the soil and represent the largest nonpoint source of organic pollutants to surface waters (Dzurik, 1990). In the Midwest, NPS pollutants from livestock operations have degraded many of the surface waters. Their effect is to generate large oxygen demands when they enter waterways.

The impact of intensive land cultivation, chemical applications and animal feedlot operations concerns all the water resource systems in a watershed (OCDE, 1986). The effects of these different land uses are not only soil erosion on the farm itself, watercourse sedimentation and pollution by chemicals, but also changes in water yields in the river basin, in water distribution and in water table levels (Hamilton and Pearce, 1986). As a matter of fact, problems have kept on increasing and the consequences are multiple. They include the reduction of productivity of fisheries (sediment deposition damages fish spawning areas or N has toxic effects on fish), agriculture; problems of hydroelectric power generation (loss of reservoir capacity by sedimentation); problems of irrigation (sediment clogs drainage ditches and irrigation canals); increased risk of flooding (large deposits of sediment overfill stream channels); losses of properties; reduction of the recreational usefulness of water bodies, and, of great concern, the impairment of human health (Crosson, 1985; Dixon and Easter, 1986; Morse and Outhet, 1986).

It has been shown that it is these mismanagement practices on areas along a waterway that have the greatest impacts on water pollution (OCDE, 1986). Economic pressures to create larger fields were the reason that brought the lands on the creek bank edge into production. According to Heathwaite et al. (1990), stream water quality is closely linked to the proximity of these intensively used areas to the stream. The role of riparian zones (p. viii) is thus of extreme importance, and they are getting increasing attention (Hamilton and Pearce, 1986).

Riparian areas are sensitive to disturbance and degradation, but can recover rapidly when managed properly (Debano and Schmidt, 1989). The riparian zone plays a critical role in the watershed's hydrology because it collects all water flow outputs from the drainage basin (Kira, 1988; Lowrance et al., 1985; Smith C., 1992). Three zones along a stream are usually distinguished: aquatic, upland and riparian (Belt et al., 1990). The aquatic zone is formed by the stream and the area of the streambed that is under water. Upland areas are characterized by vegetation and soils different from those in the riparian zone. The riparian area is located between the aquatic and upland zone and is characterized by vegetation adapted to nearness to water (Anderson and Masters, 1992). Lowrance et al. (1985) have noted that "riparian ecosystems have a great perimeter-to-area ratio, which means that this high proportion of edge interacts with adjacent ecosystems". In agricultural watersheds, such adjacent ecosystems are the watershed drainage network and the agricultural fields. It is because of this relationship that riparian ecosystems form a buffer between agriculture and streams. Buffer strips (or filter strips) have been described as "an area with often undefined boundaries, adjacent to a stream, with recognized sensitive biological and physical attributes that serve to ameliorate impacts of upland influences" (Nutter and Gaskin, 1989). Lowrance et al. (1985) have stressed the fact that the most important relationships between the riparian ecosystem and the fields are the fluxes of water, chemicals and sediment.

It is essential that vegetation is present on riparian areas because it is responsible for several beneficial effects (Debano and Schmidt, 1989). Riparian vegetation stabilizes streambanks (Lowrance et al., 1984b; Sheeter and Claire, 1989; United States State and Private Forestry Northeastern Area, 1991). This is particularly important during high flows because bank erosion can contribute to the sediment load entering the stream. Streamside vegetation helps regulate stream temperature, which in turn affects the oxygen carrying capacity. Riparian vegetation also impacts the quality of water resources because it can help mitigate or control agricultural NPS pollution in a number of ways (Smith M., 1992; Welsch, 1991).

The streamside vegetation functions as a filter by removing sediment from surface runoff. The mechanism is the following: some sediment settles out in the riparian zone because the flow speed is reduced by all the obstructions encountered in the vegetation (Welsch, 1991). Enhancement of sediment deposition by riparian forest vegetation has proven to be efficient (Lant, 1989). Total suspended sediment particles in overland flow decreased from 6480 mg/l to 661 mg/l (89.2%) in the first 19 m of a riparian forest buffer in a small Maryland watershed (Peterjohn and Correll, 1984). In two small watersheds (800 and 1400 ha) on the coastal plain of North Carolina, Cooper et al. (1987) found that 15 to 50 cm of sediment had been deposited in the last 20 years at the edge of a forest bordering a cultivated field. This corresponded to 84 to 90% of sediment removed from cultivated fields remaining in the watershed. In Virginia, Dillaha et al. (1989) evaluated the effectiveness of orchardgrass filter strips in reducing sediment loss from cropland. Three sets of plots were used. One plot in each set had no vegetative filter strip, another a 4.6 m filter strip and the third a 9.1 m one. On the 3 sets of plots, vegetative filter strips of 4.6 and

9.1 m were found to be effective with a removal of 53 to 86 and 70 to 98%, respectively, of the incoming sediment. Schlosser and Karr (1981) also provided good evidence of the reduction in sediment delivery from areas with riparian forest. They found that the rate of increase of suspended sediment loads in response to a major rainfall event was lower in reaches with riparian forest than those without.

As far as the removal of chemical pollutants from surface runoff is concerned, literature on the effects of riparian vegetation on nutrient cycling is extensive. The nutrients of greatest importance for water quality are P and N.

P is the less mobile of these 2 nutrients (Welsch, 1991). About 85% of P is bound to small soil particles (especially silt and clay) forming the sediment and to organic materials borne by runoff. P concentrations are thus reduced by the filtering action of the riparian area on sediment. Since approximately 4% of P is attached to soil particles too small to be filtered, only 80% of P is removed. According to Peterjohn and Correll (1984), concentrations of particulate P in surface runoff decreased 74% in the first 19 m of a riparian forest buffer in a small Maryland watershed. Kuenzler (1989) indicated that forested wetlands along streams can remove major percentages of P from NPS pollution. Lowrance et al.(1984b) found that 30% of P runoff from a cultivated field was retained in the riparian forest zone of a small agricultural watershed in Georgia. Dillaha et al.(1989) in Virginia showed that an orchardgrass filter strip acts as a filter for P from upland areas, removing from 49 to 85% and 65 to 95% for a 4.6 and 9.1 m vegetative filter strip. The accumulation of P in sediments within riparian forested areas also was studied in the Atlantic Coastal Plain in North Carolina (Cooper and Gilliam, 1987). It was found that the amount of P deposited was equal to the amount estimated to have been removed from the watershed. Therefore, a large portion of the P leaving agricultural fields appeared to be removed from the runoff water in the riparian areas. Schlosser and Karr (1981) found that concentrations of particulate P were reduced by riparian forests.

According to some authors (Dillaha et al, 1989; Smith M., 1992), most of the organic N forms leaving the agricultural fields and entering the vegetative filters are bound to sediment (ammonium form) because they have a strong tendency to bind to small soil (clay in particular) and organic particles present in sediment. In their experiment in Virginia, Dillaha et al. (1989) found that 66% of the N leaving field plots was sediment-bound. Smith M. (1992) also argued that N bound to sediment is more likely to be removed than N dissolved in runoff water. Total N removal is then closely related to sediment removal. Other authors like Lant (1989) and Welsch (1991) have argued that the major form of N in the soil is not held by particles. They argue that N is delivered to waterways in a dissolved form because it is soluble in water as nitrate (NO_3), and not held by soil particles. According to Peterjohn and Correll (1984), concentrations of nitrate in surface flow decreased from 4.45 mg/l to 1.76 mg/l in the first 19 m of a riparian forest buffer in a small Maryland watershed. Groundwater concentrations of nitrate decreased from 7.40 mg/l to 0.519 mg/l in the first 19 m. The overall N budget showed a 90% reduction of total N inputs to the riparian zone from surface and subsurface flow as compared to N flux leaving the riparian zone and entering a stream. Lowrance et al. (1984b) found that 68% of total N was removed within the riparian forest area of a small agricultural drainage basin. Jacobs and Gilliam (1985) showed that N was almost completely removed in subsurface flow by 16 m of a riparian forest, but that this reduction was much less where drainage tiles or ditches had been installed. Dillaha et al. (1989) also found that removal of N by an orchardgrass filter strip was effective (average of 63 and 76% for a 4.6 and 9.1 m filter strip). Other experiments (Kuenzler, 1989) indicated that forested areas along streams can intercept and remove between 22 and 89% of NPS pollution of N either in groundwater or in subsurface water.

The streamside vegetation functions as a transformer of nitrate (Pinay and Decamps, 1988). Chemical and biological processes within the riparian zone modify the chemical composition of compounds. N in runoff and debris can be converted into ammonia (NH_4), which in turn is mineralized into NO_3 by bacteria and fungi in the superficial zone (Focht and Verstraete, 1977; Guthrie and Duxbury, 1978). If the soil moisture is high enough to create anaerobic conditions in the litter and surface soil layers, denitrifying bacteria can transform NO_3 into N_2 gas - which returns N to the atmosphere (Lowrance et al., 1984b; Pinay and Decamps, 1988). This chain of reactions is highly dependent on environmental conditions: oxygen, pH, the presence of microorganisms, the degree of waterlogging... (Chalamet, 1985). Jacobs and Gilliam (1986) in their experiment in a North Carolina watershed showed that a substantial part of the nitrate in runoff was denitrified in the forested buffer strip. The loss of nitrate by denitrification was indicated by lower concentrations of nitrate in the stream. Reduction-oxidation potential values recorded near the stream indicated denitrification was likely. Others also argue that denitrification is the main ongoing process because the utilization of N by riparian vegetation is limited in winter when the vegetation is dormant, so N leaches (Kaushik and Robinson, 1976). Their results with riparian willows showed 98.5% of the N losses of a watershed were through denitrification. The role of the riparian vegetation is to provide a high organic matter, reducing environment for microbial denitrification to occur (Lant, 1989; Pinay and Decamps, 1988). Toxic chemicals such as pesticides can also be converted to non-toxic forms (Welsch, 1991). These chemicals that leave the fields are converted to non-toxic compounds by microbial decomposition, oxidation, reduction, hydrolysis and other processes within the riparian zone soil and litter.

The riparian area also functions as a sink because it can store nutrients for a long time. This role of uptake and long-term storage of nutrients is very important. Research work by Lowrance et al. (1984a) has demonstrated that the riparian zone behaves like a nutrient sink and reduces nutrient concentrations in aquifers before they enter the stream. Processes within the riparian zone transformed inorganic N from fields (76% NO_3-N, 6% NH_4-N, 18% organic N) into organic N in the streamside (10% NO_3-N, 14% NH_4-N, 76% organic N). Concentration differences between agricultural fields and riparian forest clearly indicated the riparian vegetation's ability to act as a sink. Furthermore, Fail et al. (1987) measured the production rates and tissue nutrient concentrations of woody plants of a riparian zone in Georgia. They observed higher branch wood and leaf nutrient concentrations on the test sites than on the reference sites. Some estimates indicate that 25% of the N removed by streamside trees is used for growth. So it is stored for long periods of time in woody material (Welsch, 1991). Later on, this is taken away as logs or other forest products. Nutrients can also be passed up the food chain when riparian plant tissue is consumed by animals. If the riparian area is very wet, nutrients in leaf litter can be stored as peat for a long time.

It was interesting to note that literature showed controversy over the process by which N removal occurs within the riparian vegetated buffer. Jacobs and Gilliam (1985), Kaushik and Robinson (1976), Lowrance et al. (1984b) and Pinay and Decamps (1988) argued that assimilation by vegetation is insignificant and that denitrification is the major removal process.

Literature results therefore demonstrated that riparian ecosystems - provided tiles or other types of drainage are absent - are effective in filtering sediment and reducing nutrients (N and P) and pesticides delivery to streams, by deposition, plant uptake and different biochemical processes. This reduces NPS pollution and protects surface water and groundwater quality. These research results thus encourage the use of vegetated buffer strips along waterways as a means of maintaining acceptable water quality (Fail et al., 1987; McColl, 1978; Norris and Shabmann, 1988; Nutter and Gaskin, 1989). This effectiveness is however not total and varies, depending on the season (variation of flow of pollutants: high during storms for example), the topography, the quantity of inputs to the riparian corridor from upland agricultural activities and the width of the riparian zone (Lant, 1989).

Research data documenting the role and importance of riparian buffer strips in reducing NPS pollution was extensive. But information on the criteria that would be best to use in locating riparian areas vulnerable to NPS pollution and in need of filter strips was surprisingly limited. Determining site sensitivity however appeared to largely depend on soil erodibility and degree of slope (Neuman, 1987).

The decision concerning the width of buffer strips is also an important one (Smith M., 1992). No study seemed to agree on which factors are of greatest concern. Each used a different width (Cooper et al., 1987; Dillaha et al., 1989; Jacobs and Gilliam, 1985; Magette et al., 1989). Data on how to determine a suitable buffer width was missing.

There was a similar lack of literature concerning the type of vegetation to be used on a buffer strip. As far as the vegetation composition of a filter strip is concerned, research has shown we can manipulate the riparian zone for various management objectives (Oliver and Hinckley, 1987). To date research has focused on the characterization of the variety of streamside plant species (Winward and Padgett, 1989). Studies on the effectiveness of filter strips have mainly been single species oriented. A mixture of different vegetation cover types was rare (Agriculture Canada, 1992).

Criteria for the determination of riparian areas sensitive to NPS agricultural pollution, buffer strip width, as well as filter strips vegetation composition were therefore topics of interest because they are not fully understood. Looking into these different points can help explore the possibilities that may exist.

Constructing a buffer strip, once these different aspects are defined, thus appears to be an excellent technique to restore the riparian ecosystem and mitigate water pollution. But this rehabilitation involves additional aspects. In particular, land use practices that reduce losses of sediment and nutrients from agricultural fields can help protect the resources of a watershed. They are called Best Management Practices (BMP's) and are designed to reduce harmful impacts on the environment while preserving the profitability of farmers (Iowa State University Extension, 1993). A lot of agencies are interested in the use of BMP's and quite a lot of research is conducted on watersheds.

On-farm trials in Kansas have shown that the use of fall-seeded cover crops reduces erosion (Jost, 1992). Developing a more appropriate crop rotation can also be useful (Reznicek, 1992). Another way to cope with the problem of erosion is to change the patterns of crops and arrange them in strips along the contour (Iowa State University Extension, 1993). This slows down the water and retains the soil: erosion is reduced by 75%. Contour buffer strip design alternates strips of perennial vegetation with crop strips. This permanent vegetation slows down runoff and traps sediment. A terrace structure on a long slope can also help the soil stay in place. Grassed waterways are another technique to reduce erosion by slowing down the water and forcing it to drop the soil it carries.

Avoiding soil disturbance is a way to mitigate erosion. The type of tillage system is thus important. Residue management systems reduce the use of tillage, which curtails soil erosion (Gillespie, 1992; Iowa State University Extension, 1993; Prato and Wu, 1991). The crop residue cover they leave has been shown to reduce erosion by 50% compared to a tilled field (Melvin, 1990). Crop residue controls erosion because it protects the soil surface from the rain impact and slows down runoff water. No-till is used on highly erodible land (Shouse, 1990a). Results showed that after repeated years of no-till, the higher number of macropores in the soil increases water infiltration. Ridge-till is another practice that has similar benefits (Shouse, 1990b).

Besides reducing soil erosion, conservation tillage practices also result in less chemical losses (McFadden, 1990; Neubeiser, 1987; Sauer and Daniel, 1987). Mostaghimi et al. (1988) found that no-till, besides being effective in reducing runoff and sediment losses, was very effective in reducing P losses. With ridge-till, there is a reduction by at least half the amount of herbicide used in conventional tillage because herbicide is applied in a band only over the crop row (Betts, 1987). Using cover crops that have an allelopathic effect on weeds is also helpful to mitigate the use of herbicides. Fertilizer management on the land is a key factor affecting pollution control. There is a natural tendency for each farmer to overestimate the amount of N needed by crops for instance (Iowa State University Extension, 1993). BMP's thus include a rate of chemical application based on realistic yield goals for each field, soil test, timing of application and choice of chemical formulation (Puginier, 1991). The Big Spring Basin project in Northeast Iowa has shown that it is possible to reduce N fertilizer use and yet maintain or even increase yields (Mitchell, 1992). Splitting N applications seemed to enhance efficient N utilization and reduce total N losses to groundwater (Kanwar and Baker, 1988; Pirog and DeWitt, 1991). Cover crops are also an excellent source of N for crops, which can help reduce fertilization (Draeger, 1990).

Within a watershed rehabilitation project, these BMP's have to be chosen according to each situation because each NPS agricultural pollution problem is unique (Melvin, 1990; Merrill et al., 1983). Norris and Shabmann (1988) have recommended combining a number of BMP's to increase the effectiveness of the watershed pollution management strategy. Even though riparian buffer strips can be considered to be an extremely efficient strategy to control NPS water pollution, they can not replace BMP's applied upland (Iowa State University, 1993; Smith M., 1992). Combination of a riparian buffer strip with other BMPs is thus necessary for effective water pollution reduction.

However, the management of watersheds has been unsuccessful, partly because concentration has been almost exclusively on these biophysical aspects. Socioeconomic aspects have been mostly discarded. One example dealing with cropland erosion illustrates the key role these latter aspects play (Crosson, 1985). The difference between off-farm and on-farm damages does affect farmers' incentives to control erosion. Because off-farm damages are not borne by the farmer, he has no incentive to reduce them, unless public intervention forces him to do so. The farmer himself, however, bears the cost of lost productivity, giving him the incentive to control erosion to reduce the cost.

It is therefore important to devise systems to enhance environmental protection that are simultaneously compatible with a vigorous agriculture. This is why, in the Bear Creek watershed study, it has appeared necessary not to consider only the protection measures as a whole, but to take into account the existence of individual farmers. Demonstrating to them the need for some modifications in agricultural practices will come from an analysis of the consequences for them. The first step in the process involves the identification of critical riparian zone areas along Bear Creek that may benefit from the establishment of buffer strips. These Bear Creek buffer strips (BCBS) represent a basis for future research in the project.

CHAPTER 3. DESCRIPTION OF THE STUDY SITE

The Bear Creek watershed project

Because of the ecological importance of riparian areas in maintaining natural functioning between terrestrial and aquatic ecosystems, there is interest in Iowa to promote riparian zone management on farmland (Menzel and Schultz, 1993). The Bear Creek watershed project is part of a 5-year project, focusing on management of streamside areas in agricultural lands for ameliorating NPS pollution. It has been undertaken by the agroecology interdisciplinary team of the Leopold Center for Sustainable Agriculture. The objectives of the project are to assess environmental (biotic, geophysical and landscape) and socioeconomic characteristics of the watershed and to identify riparian areas vulnerable to NPS pollution. From these results, both riparian and upland, landscape management practices will be devised. Subsequently, they will be implemented through cooperation with local farmers and resource management agencies. Evaluation for technical effectiveness, economic efficacy and social acceptance will follow.

The Bear Creek watershed is located in Story, Hardin and Hamilton Counties (Figure 1) and is typical of watersheds that lie in predominantly agricultural landscapes. Soils are particularly fertile in this part of the state because they are located within the limits of the last glacial advances in the upper Midwest region, about 10,000 years ago: the Des Moines lobe. This end moraine forms the richest farmland in the area. Intensive agriculture results in NPS water pollution, alteration of channels, loss of natural ecosystems and disruption of wildlife habitats and populations.

Characteristics of the Bear Creek watershed

The Bear Creek watershed has a very narrow shape and extends over 7659.5 ha, which are drained by Bear Creek (Figure 2). This third order stream (p. viii), which drains level to gently undulating topography, is typical of north-

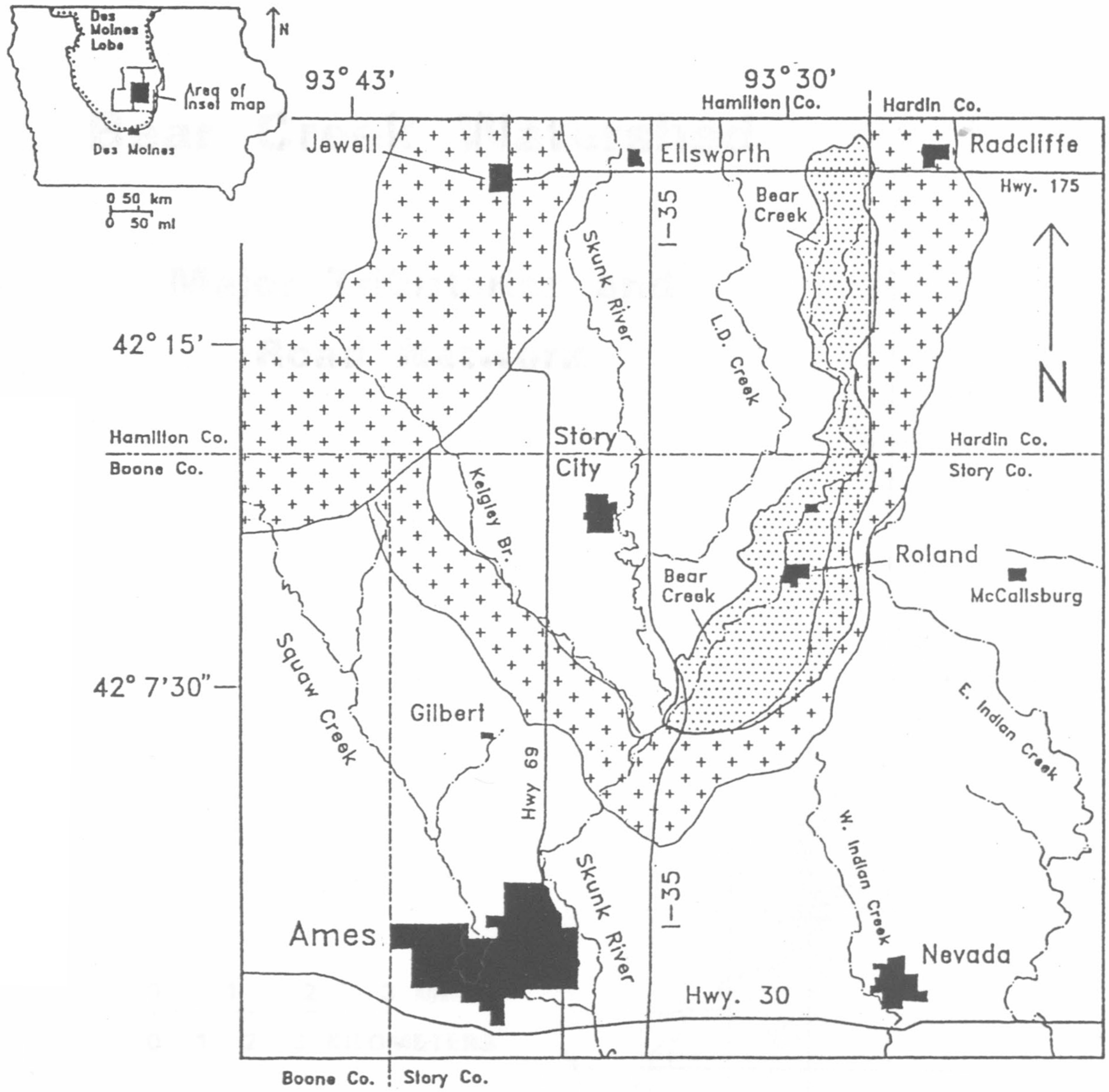


Figure 1. Location of the Bear Creek watershed in Iowa

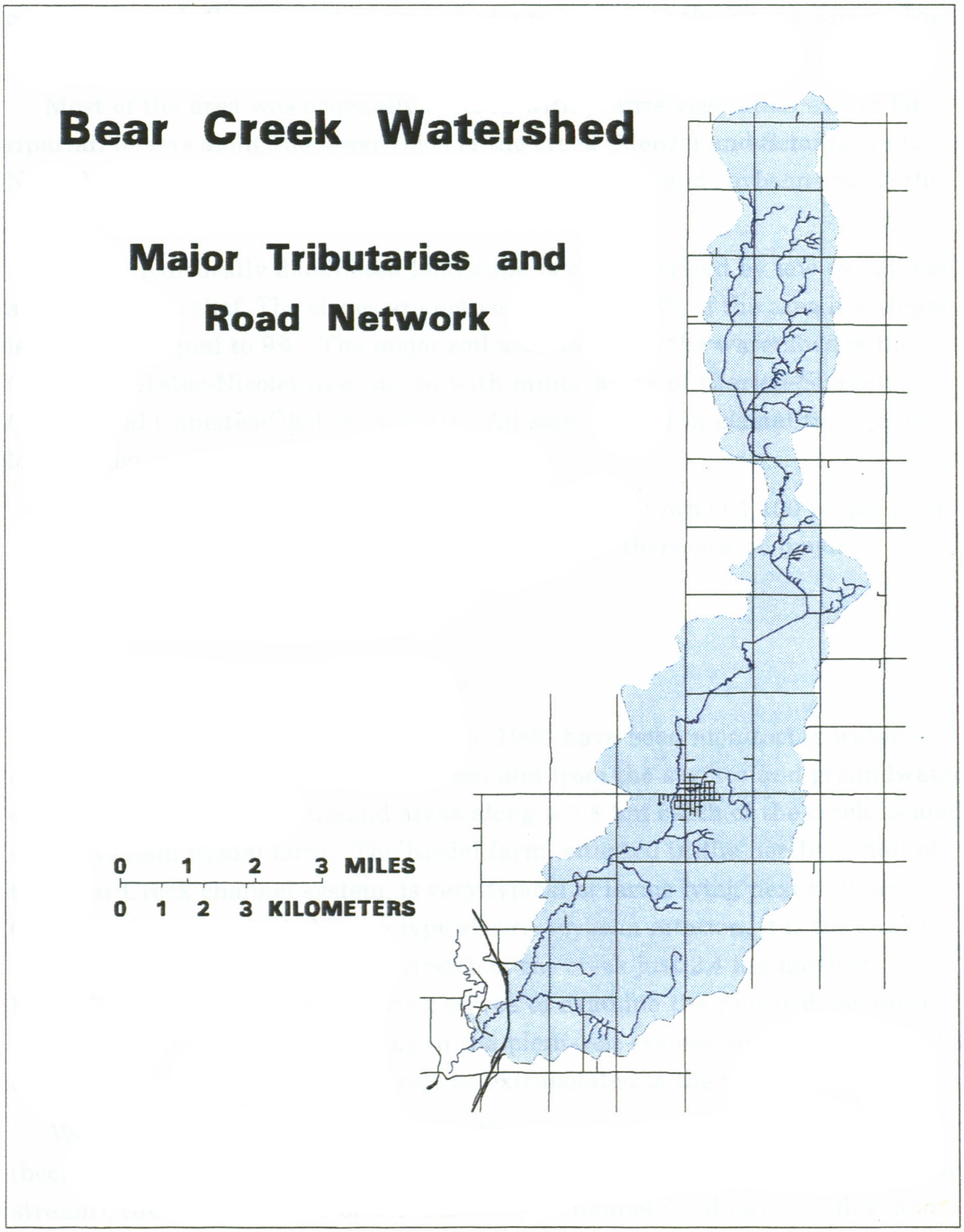


Figure 2. The Bear Creek watershed, its major tributaries and road network

central Iowa. It flows for 74.3 kms before emptying into the Skunk River. The tributary sytem (including intermittent waterways) is 38.2 km in length.

Most of the area was originally covered with prairie vegetation except for riparian forests along the lower third of the creek (Menzel and Schultz, 1992). Nowadays, most of the area is in cultivation with corn and soybeans being the major crops.

The agriculturally dominated landscape is characterized by low elevations and moderate relief. The slopes are not very steep: 96.8% of the area has slopes less than or equal to 9%. The major soil association in the watershed is the Clarion-Webster-Nicolet association with minor areas of Clarion-Storden-Coland and Canisteo-Okoboji-Nicolett. All soils formed in glacial till or from local alluvium from till.

The area was first settled in the 1850's. Roland, a town of 1,100 people is the only community in the Bear Creek watershed and there are no major recreational areas.

Results of the geophysical survey

Continued field measurements since 1990 have been monitoring water quality at 16 locations along the stream and from the surface and groundwater of the riparian zone and upland areas along a 0.8 km reach of the creek located on the Ronald Risdal farm. The Risdal farm, situated in the northern half of the Bear Creek channel system, is very typical of farms lying next to Bear Creek in the watershed. With a typical corn-soybean rotation, it is the site of the BCBS research, with a 2 km stretch of the creek just 2.4 km north of Roland. This intensive monitoring serves to examine the physical, chemical and biological processes occurring in the plant-soil system near the edge of the creek. These data will subsequently be extrapolated to the watershed scale.

Water quality is investigated at 3 different scales: the bedrock aquifer (because of the presence of multiple aquifer units that could discharge into the stream), the surface water of the Bear Creek channel (evaluation of flow and chemical transport to the stream from till, alluvial and shallow bedrock aquifers and drainage tiles) and one section of the creek (the experimental buffer strip).

As far as water NO_3-N levels are concerned, there is evidence of pollution (Appendix A). Results from 1993 sampling showed that stream NO_3-N concentrations are correlated to fertilizer applications. They exceed Environmental Protection Agency (EPA) standards for drinking water (10 mg/l of NO_3-N) in the headwaters. Levels in the tiles are also tied to N fertilizer application and exceed EPA limits in spring and summer.

Pesticide residues have also been detected in the water (Appendix B). Atrazine concentrations in the creek are particularly high in the summer. Levels exceeding the EPA standard (3 ug/l) are found in the headwater reaches. Atrazine is present in tiles at almost every sampling date. Although individual tile concentrations do not exceed the EPA limit, the creek accumulates their residues.

Databases for Bear Creek

As part of the environmental assessment of the Bear Creek watershed, the Geographic Information Systems (GIS) tool has been used, starting in 1992. GIS is a computer system capable of manipulating and displaying geographically referenced information. The use of such spatial data allows one to analyze and interpret landscape features deemed important for particular analyses. Environmental study of watersheds is therefore enhanced with GIS. Data entry to date has provided different layers of information necessary to pursue further analysis. The main layers completed include: the road network of the Bear Creek watershed area; the main channel for Bear Creek and its tributaries; the soils for the watershed; the delineation of the watershed; different layers specifically related to the Risdal site; the water sampling locations; the 1992 crop and groundcover for the watershed; the ownership of land parcels in the watershed and the topography of the Bear Creek watershed.

CHAPTER 4. OBJECTIVES OF THE STUDY

The goal of this particular Bear Creek watershed study was to identify riparian areas that are vulnerable to excessive NPS pollution, and to recommend the type of vegetation cover and the width to establish in these areas. The purpose was to recommend ecologically sound management practices that have the potential to reduce NPS pollution of the stream, therefore preserving the water resources of the watershed.

The specific objectives of the study were:

1- To identify areas along Bear Creek that are vulnerable to NPS pollution;

2- To recommend a buffer strip width effective enough to reduce NPS pollution in the creek;

3- To identify the type of vegetation that should be established on the BCBS.

CHAPTER 5. METHODS OF THE STUDY

Identification of areas along Bear Creek that are vulnerable to NPS pollution

GIS was used to identify the vulnerability of specific portions of the Bear Creek watershed to NPS pollution. The analysis was performed in Arc/Info (Version 6.1.1, December 1992) using layers of the watershed delineation, Bear Creek and its tributaries, the 1992 ground cover for the watershed and the soils for the watershed with their associated ISPAID (Iowa Soil Properties and Interpretation Database) (Iowa Agriculture and Home Economics Experiment Station Cooperative Extension Service, 1990) data.

Three soil characteristics, as defined by the United States Soil Conservation Service, were selected as criteria to locate where the stream system would benefit by some protection of the riparian zone.

The first criteria was the erosion potential, represented by the erodibility factor K, combined with the slope. The second criteria was flooding frequency and the third criteria was drainage class. For each of these factors, a map was developed for the whole watershed.

Erosion potential was deemed most important because areas very susceptible to soil erosion greatly contribute to the delivery of sediment and sediment-borne pollutants to the water. The K factor indicates the susceptibility of a soil to sheet and rill erosion by water. It is based on the percentage of silt, sand and organic matter, and on soil structure and permeability. In Iowa, values of K range from 0.05 to 0.43 (Iowa Agriculture and Home Economics Experiment Station Cooperative Extension Service, 1990). The slope is the incline of the soil and is expressed as a percentage. The Bear Creek watershed soils fall into the 0-2%, 2-5%, 5-9%, 9-14% and >14% slope classes. Values for the K factor and the slope were combined to obtain a matrix classifying the erosion hazard into low, medium and high categories (Figure

3). The higher the K value, the more susceptible the soil is to erosion. The greater the slope, the higher the erosion potential. The rating of low, medium and high erosion hazard was assigned, based on a consideration of the importance of each factor in erosion risk (Michael Thompson, personal communication). An a.m.l. (Arc Macro Language) program was then generated to produce a map of the watershed showing the areas of each erosion category.

K factor value

Percent slope	0.05 – 0.2	0.2 – 0.30	0.30 – 0.43
0 – 2	L[a]	L	M
2 – 5	M[b]	M	M
5 – 9	M	H	H
9 – 14	M	H	H
> 14	H[c]	H	H

a. L stands for low erosion hazard.
b. M stands for medium erosion hazard.
c. H stands for high erosion hazard.

Figure 3. Erosion hazard ranking for the Bear Creek watershed

Flooding frequency potential was the next criteria to be investigated. It is the temporary covering of soil with water from overflowing streams and runoff from adjacent slopes (Iowa Agriculture and Home Economics Experiment Station Cooperative Extension Service, 1990). The ability of these waters to carry material from surface runoff contributes to water pollution. Areas in the watershed were identified using ISPAID classifications as being subject to either rare (unlikely but possible under unusual weather conditions), occasional (average of once or less in 2 years), common (likely under normal conditions), frequent (average of more than once in 2 years), or ponded (standing water on soils in closed depressions for short durations) flooding events. An a.m.l. program was used to obtain a map of the distribution of these flooding frequency types.

Identification of poorly drained areas was the third criteria. The drainage of a soil is related to the frequency and duration of saturation. The low infiltration rates of poorly drained areas make them susceptible to surface runoff. An a.m.l. program was set up to select areas in the watershed that have the ISPAID classifications of somewhat poor, somewhat poor to poor, poor, poor to very poor and very poor drainage.

A whole watershed NPS pollution map was developed combining these 3 analyses (Figure 4). An a.m.l. program was used to combine the 3 layers of information. Factors were combined to obtain 3 levels of vulnerability: low, medium and high as shown in Table 1. Among the 2209 polygons which make up the soil coverage for the Bear Creek watershed, 177 had characteristics identifying them simultaneously as medium erosion hazard and as high vulnerability (ponded flooding frequency and very poor drainage). Since these flooding and drainage attributes result in poor cropping capabilities, it is beneficial to take these areas out of production. They were thus classified as highly vulnerable for water pollution.

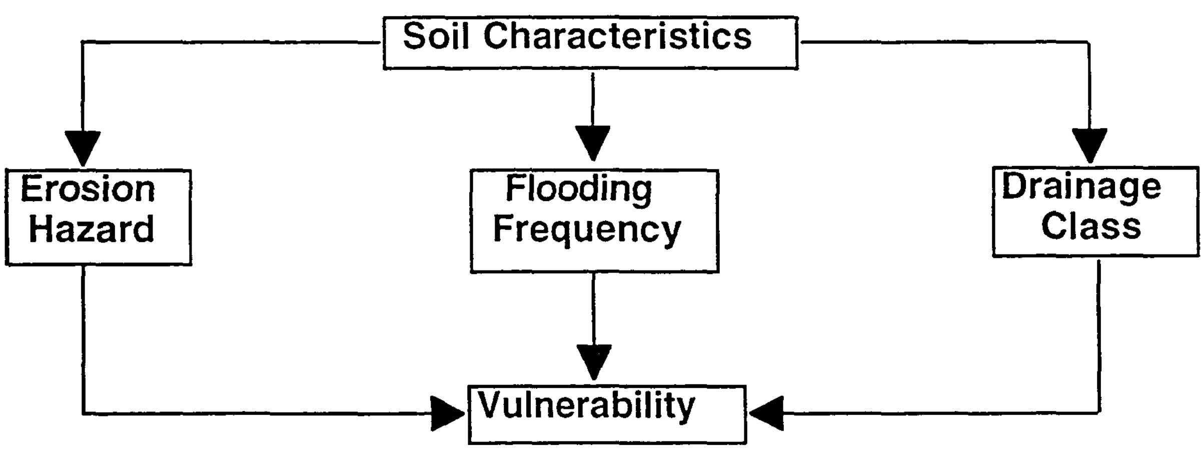


Figure 4. Vulnerability identification process

Table 1. Vulnerability potential for the Bear Creek watershed

Vulnerability type	Erosion hazard	Flooding frequency	Soil drainage class
Low	Low	Rare, None	Excessively to well and moderately well
Medium	Medium	Common, Occasional	Somewhat poor Somewhat poor to poor
High	High	Frequent, Ponded	Poor, Poor to very poor Very poor

As described in Chapter 2, riparian areas are located at the interface between the terrestrial and aquatic ecosystems. They represent a high potential for dealing with NPS water pollution mitigation. We were thus interested in identifying the vulnerability of the riparian zone along Bear Creek. The soils coverage was clipped to a 20 m width of riparian zone and the same previous vulnerability analysis run. This produced a map of areas susceptible to contribute to NPS pollution in the riparian zone. Only after comparison with land use in this same zone could critical areas be identified. As with the whole watershed case, 20 records among a total of 716 were identified as belonging at the same time to medium and high vulnerability categories for similar reasons as before. These records were reassigned to highly vulnerable areas too.

Using the subprogram Tables in Arc/Info, statistics on areas were calculated for each of the maps. The length of the main channel and tributaries falling into different categories was also measured using a digitizing tablet.

Buffer strip width

This recommendation was based, for the most part, on current literature on the subject. These major sources of information were compared to come up with a recommendation for Bear Creek. Created with an a.m.l. program, a map indicating land capability classes in the 20 m riparian zone was used to guide the determination of buffer strips' width. Corresponding areas were calculated using the subprogram Tables in Arc/Info.

Buffer strip vegetation

Based on literature, a discussion of the kind of riparian cover to establish tried to discern which type(s) of vegetation could be most useful. To compare the location of vulnerable areas to current management practices, maps of land use in the Bear Creek watershed and in the riparian zone were used. They were developed with a.m.l. programs. The one for the riparian zone used the ground cover coverage clipped to a 20 m riparian width. As with the other maps, statistics on land use areas were obtained using the subprogram Tables in Arc/Info.

The vegetation composition of the buffer strips to establish in the watershed was then studied. A decision model chart was developed, based on soil information critical for plant growth and on important ecological characteristics of the species. The guide comprises a soils table, different species tables and a vegetation selection diagram.

CHAPTER 6. RESULTS AND DISCUSSION

Identification of areas vulnerable to NPS pollution

Although the importance of riparian zones is widely recognized, documentation on criteria to use to locate areas having a potential to contribute to NPS pollution is very limited. Different field soil erosion susceptibility ratings have been developed (Armstrong et al., 1990; Crafton, 1987; Van Der Puy, 1987), but there is no information concerning riparian zones in particular. However, for soils located next to watercourses, Neuman (1987) has recommended assessing soil erodibility and degree of slope to determine a site's potential to erode and produce stream sedimentation.

Erosion hazard, flooding frequency potential and poor soil drainage were the criteria selected to identify areas vulnerable to NPS pollution in the Bear Creek watershed. Many other physical characteristics could have been chosen, but these three were deemed more relevant to the study because of their link to the potential for pollutant delivery to water. The choice of such criteria can vary according to the final goal. In the Bear Creek watershed project, the goal is to improve stream water quality by reducing surface runoff into the channel and intercepting subsurface flow within the riparian zone to decrease chemical discharge into the stream. Since surface water quality inprovement is the priority, the selected criteria were deemed adequate.

Erosion hazard

The identification of areas vulnerable to NPS pollution in the riparian zone required the use of a particular width. Several different widths could have been studied. However, since there is little information on how to determine a suitable riparian zone width and no agreement on the subject (further information can be found in Buffer Strip Width section), a 20 m width was selected to match the current research on BCBS at the Risdal experimental farm site.

The erosion hazard analysis over the whole watershed showed that 52.2% of the drainage basin had a medium or high erosion potential (Table 2 and Figure 5). High risk sites were mostly located in the northern half and southern quarter of the watershed. Medium risk areas were more scattered, with a noticeable concentration just north of the narrowest portion of the watershed and in the southern third portion. About 27 km of the creek length were identified as presenting a medium erosion hazard and 6.8 km a high hazard. Along 3.0 km, one side was classified as medium and the other as high. Close to 9 km also had either one high erosion risk streambank and the other low erosion risk, or one medium erosion streambank and the other low erosion. These areas are potential contributors to stream sedimentation and need sound management to improve the water quality of Bear Creek and its tributaries. A permanent riparian vegetation community could be one way to reduce delivery of sediment and chemicals to water. Since riparian areas prone to erosion were located on both sides of the stream, it appeared essential to recommend the protection of both banks of waterways. Sensitive areas (medium or high erosion potential) not located in the riparian zone could probably benefit from some conservation practices as well. These could include the application of BMP's or the establishment of a permanent vegetation cover to reduce runoff volume reaching the stream.

Table 2. Erosion hazard in the Bear Creek watershed

Erosion hazard	Area (ha)	%Area*
Low	3664.0	47.8
Medium	2988.7	39.0
High	1006.8	13.2

* Percent of total watershed area.

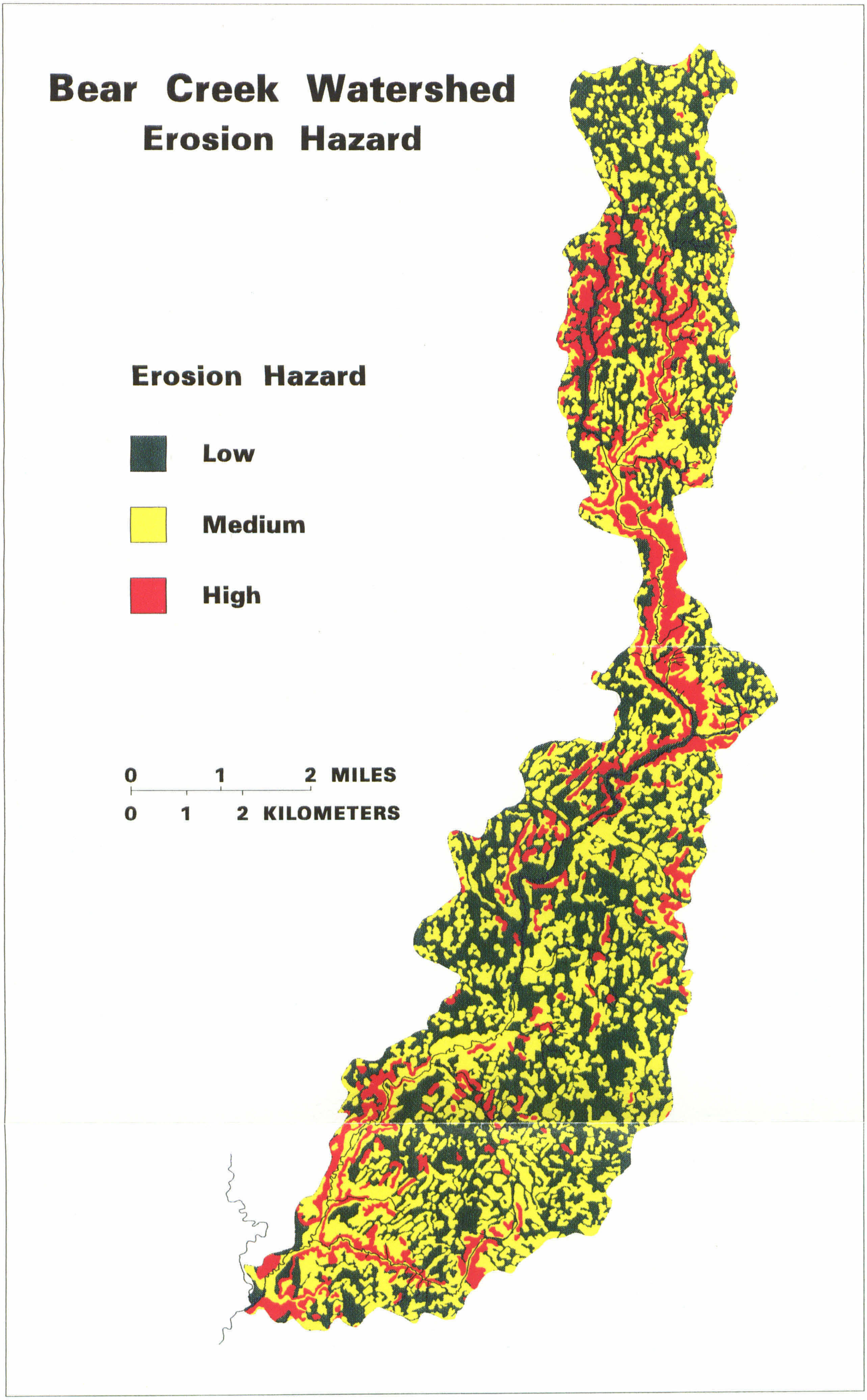


Figure 5. Bear Creek watershed erosion hazard map

Flooding frequency

The analysis of flooding frequency potential over the whole drainage basin indicated that soils with occasional, frequent or ponded flooding types are dominant over soils with rare or common flooding (Table 3 and Figure 6). Ponded soils are scattered over the watershed. Occasionally and frequently flooded soils are located in the riparian zone with 18.5 km of the stream lying along frequently flooded soils and 19.9 km along occasionally flooded soils. A way to prevent flooding events from delivering large amounts of pollutants to the stream could be the presence of permanent vegetation on the banks. It would act as a barrier to filter most of the water-borne material.

Comparing the location of soils with high erosion hazards and flooding potential in the riparian zone showed a correspondence between medium erosion and frequent flooding. In the northern part of the watershed, medium erosion risk riparian soils also had occasional flooding potential. The potential vulnerability of these areas is therefore high. This reinforces the need for conservation land use practices in the riparian zone. The same is true for the correspondence between upland ponded areas with medium erosion risks.

Table 3. Flooding frequency in the Bear Creek watershed

Flooding type	Area (ha)	%Area*
Rare	0	0
Occasional	208.4	2.7
Common	0	0
Frequent	188.5	2.5
Ponded	218.8	2.9
None	7043.8	91.9

* Percent of total watershed area.

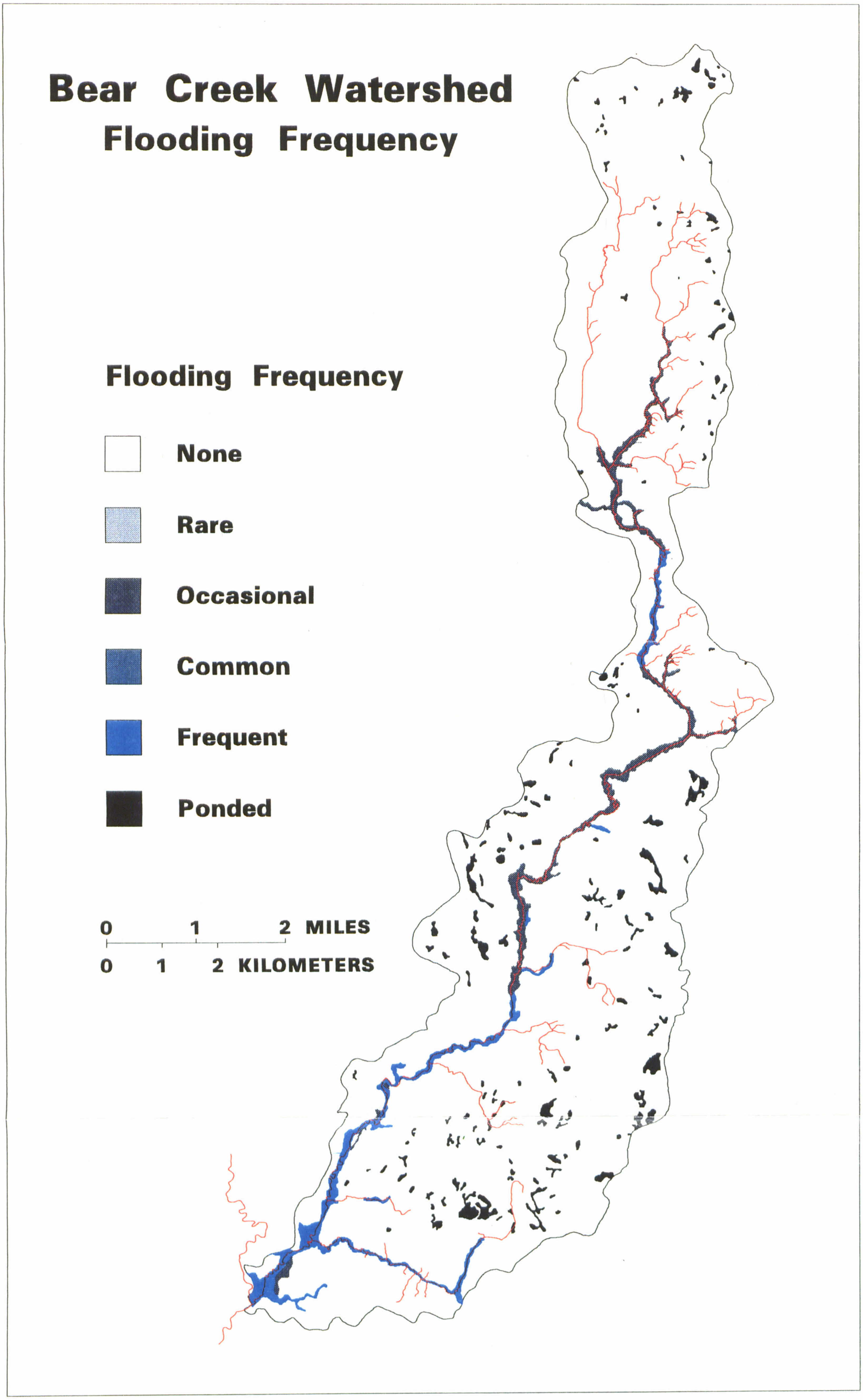


Figure 6. Bear Creek watershed flooding frequency map

Soil drainage class

Identification of poorly drained areas showed that half the watershed soils have a somewhat poor to very poor drainage (Table 4 and Figure 7). Somewhat poorly drained areas are frequent in the upland. Poorly drained areas are dominant (35.5%) and located both in the upland and along the stream. In the riparian zone, 49.8 km were identified as poorly drained. This portion of the drainage network is likely to promote NPS pollution by enhancing surface runoff. These areas should thus receive special attention in terms of management practices. Vegetation adapted to these poorly drained soils could trap some of the sediment and chemical pollutants before they enter the stream. It is interesting to note that poorly drained areas along the creek possibly were wetlands a long time ago. They would therefore represent potential sites for riparian wetland restoration, which act as filters for sediment and nutrients in a way similar to vegetated buffer strips (Kuenzler, 1989; Thompson, 1992). Very poorly drained areas along first order tributaries in the south of the watershed are examples of such potential sites. Very poorly drained areas outside the riparian zone could also be choice sites for wetland restoration. They could reduce water quality degradation as well (Gordon et al., 1986; Nutter and Gaskin, 1989; Thompson, 1992; Welsch, 1991).

Table 4. Poorly drained areas in the Bear Creek watershed

Drainage class	Area (ha)	%Area*
Excessive to somewhat to well to moderately well	3800.5	49.6
Somewhat poor	871.3	11.4
Somewhat to poor	48.0	0.6
Poor	2720.9	35.5
Poor to very poor	0.9	<0.1
Very poor	217.9	2.8

* Percent of total watershed area.

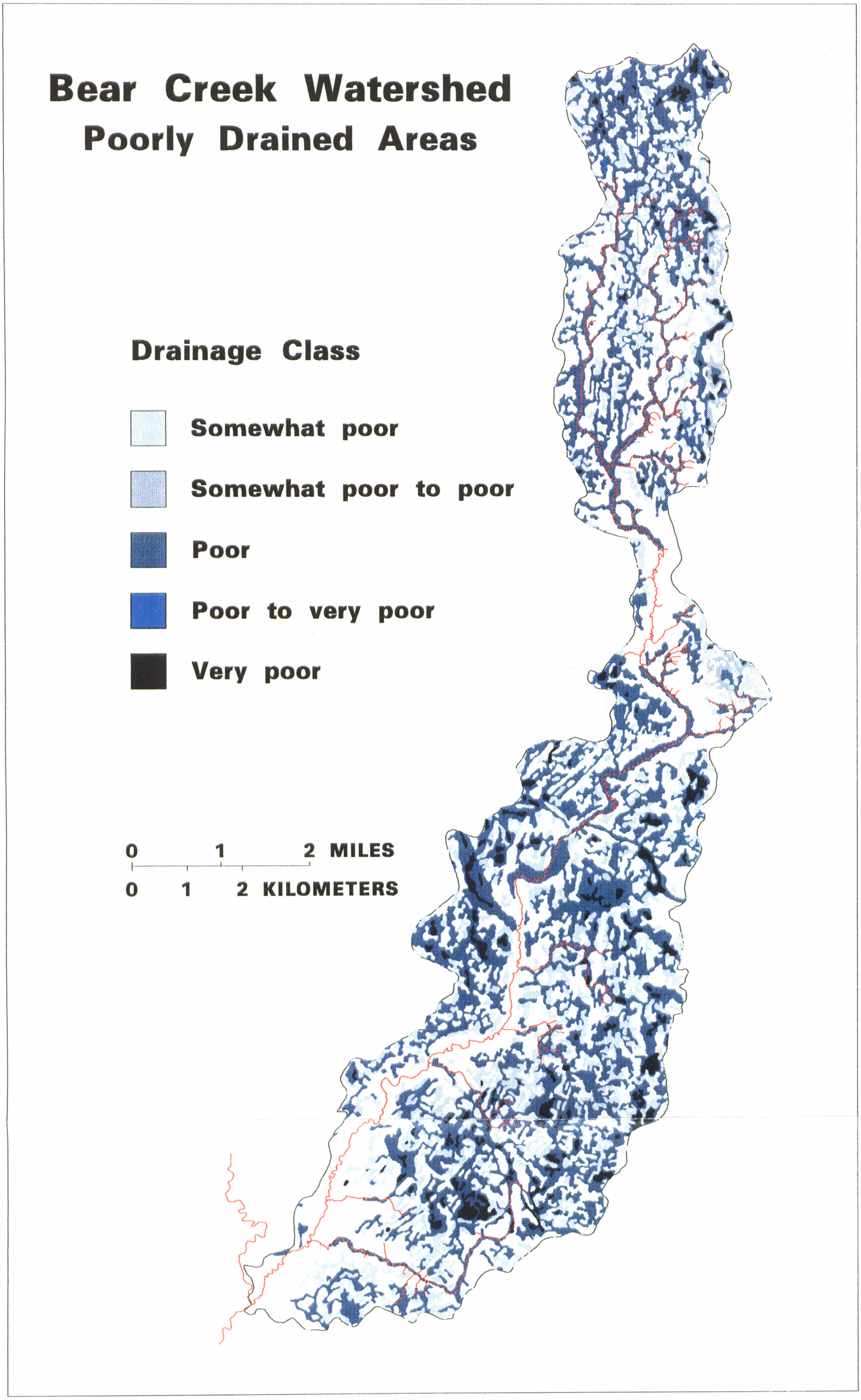


Figure 7. Bear Creek watershed poorly drained areas map

Vulnerability analysis

From the vulnerability analysis, it was clear that a very large portion of the watershed could potentially contribute to water pollution (Table 5 and Figure 8). Nearly 91% of the area was identified as having a medium or high potential. Sensitive areas were scattered throughout the drainage basin. Highly vulnerable riparian zones were mostly located in the northern and central parts. Along the riparian zone, 21.7 km belonged to the medium vulnerability category and 45.8 km to the high category. On 6.4 km, one side was classified as medium and the other as highly vulnerable. This means NPS pollution in the Bear Creek watershed could be reduced by bringing adequate management practices to these vulnerable riparian areas. Outside the riparian zone, susceptible areas would also benefit by some protection measurements since they are responsible for some sediment production as well as chemical contamination.

Table 5. Summary of NPS pollution vulnerability in the Bear Creek watershed

Vulnerability type	Area (ha)	%Area*
Low	697.9	9.1
Medium	3330.9	43.5
High	3630.7	47.4

* Percent of total watershed area.

Further analysis within 20 m on either side of the creek indicated that streamside areas could potentially contribute sediment and chemicals to creek water: about 77.5% of the creek length were identified as medium or high risk areas (Table 6 and Figure 9). These areas are especially important in maintaining high water quality. Not only can they be the immediate source of NPS pollutants, but they also act as the last buffer zone for potential upland NPS pollution that moves downslope towards the creek. Their potential

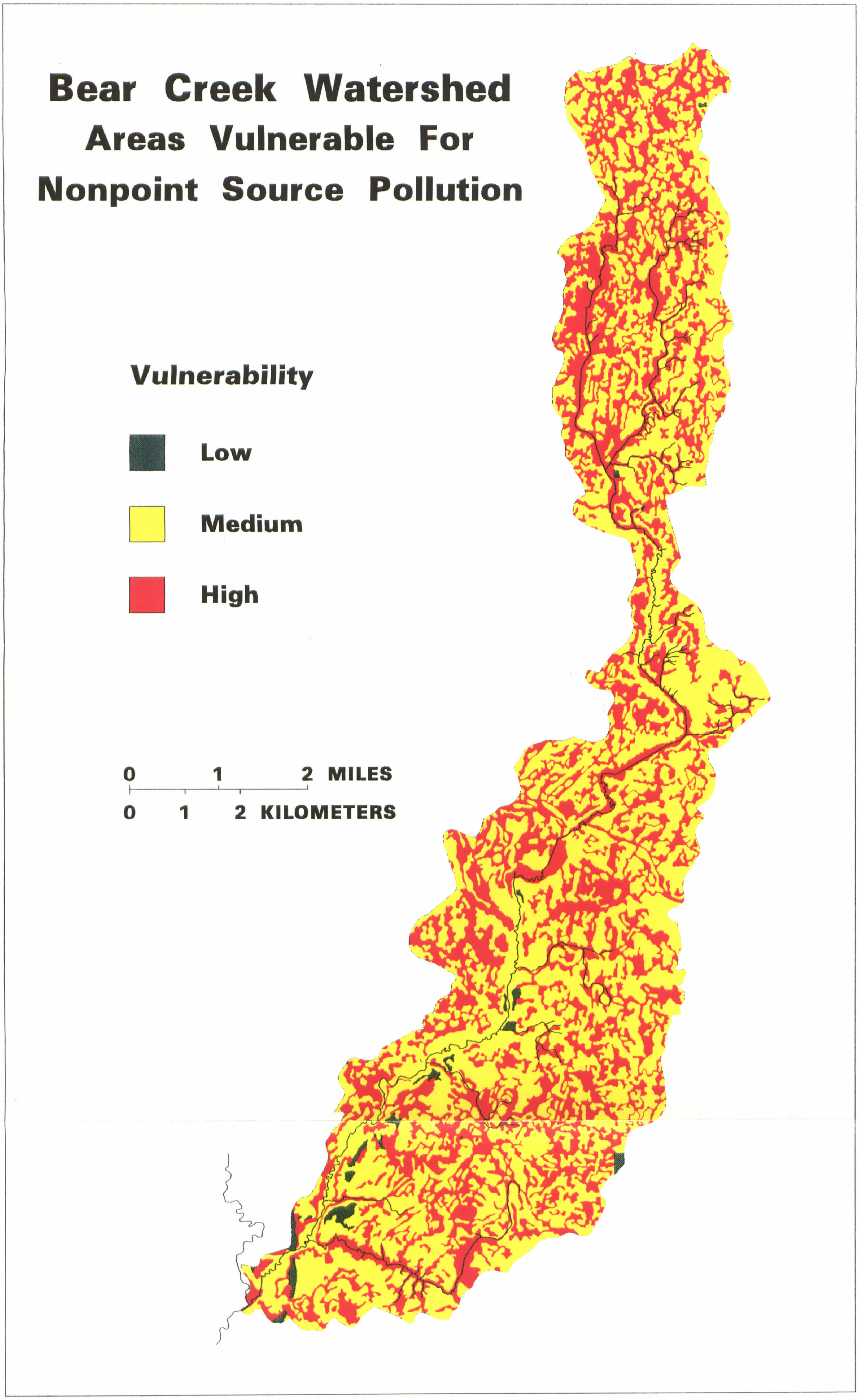


Figure 8. Bear Creek watershed NPS pollution vulnerability map

Table 6. Riparian zone (20 m width) NPS pollution vulnerability in the Bear Creek watershed

Vulnerability type	Area (ha)	%Area*
Low	81.3	22.5
Medium	97.3	27.0
High	182.0	50.5

* Percent of total 20 m wide riparian zone.

contribution to NPS pollution cannot be overlooked and requires management practices capable of mitigating their vulnerability.

These data indicate that a large portion of the Bear Creek watershed and its riparian zone have either a medium or a high potential to contribute to NPS water pollution. Areas along the stream require special attention. The recommendation is thus to establish a vegetated buffer on areas identified as particularly vulnerable along any perennial or intermittent watercourse and around any other body of water (lagoons, ponds or future restored wetlands, if any) in the drainage basin. These buffer strips should follow the curvature of the stream or body of water. The need for BCBS is summarized in Figure 10. The recommendation of conservation practices can be extended to vulnerable areas other than within the riparian zone. In all cases, a multi-species buffer strip is recommended. Such a strip could contain various combinations of trees, shrubs and grasses. The actual combination of species and percentage of each species can be varied by area and by the objectives of the landowner.

In conclusion, assessment of the combined erosion hazard, potential for flooding and soil drainage in the Bear Creek watershed have shown the presence of numerous vulnerable areas. Although upland areas have been located, emphasis is on the develpoment of alternative riparian land uses, vegetated buffer strips, that will lead to reduced impact of NPS pollution on the creek.

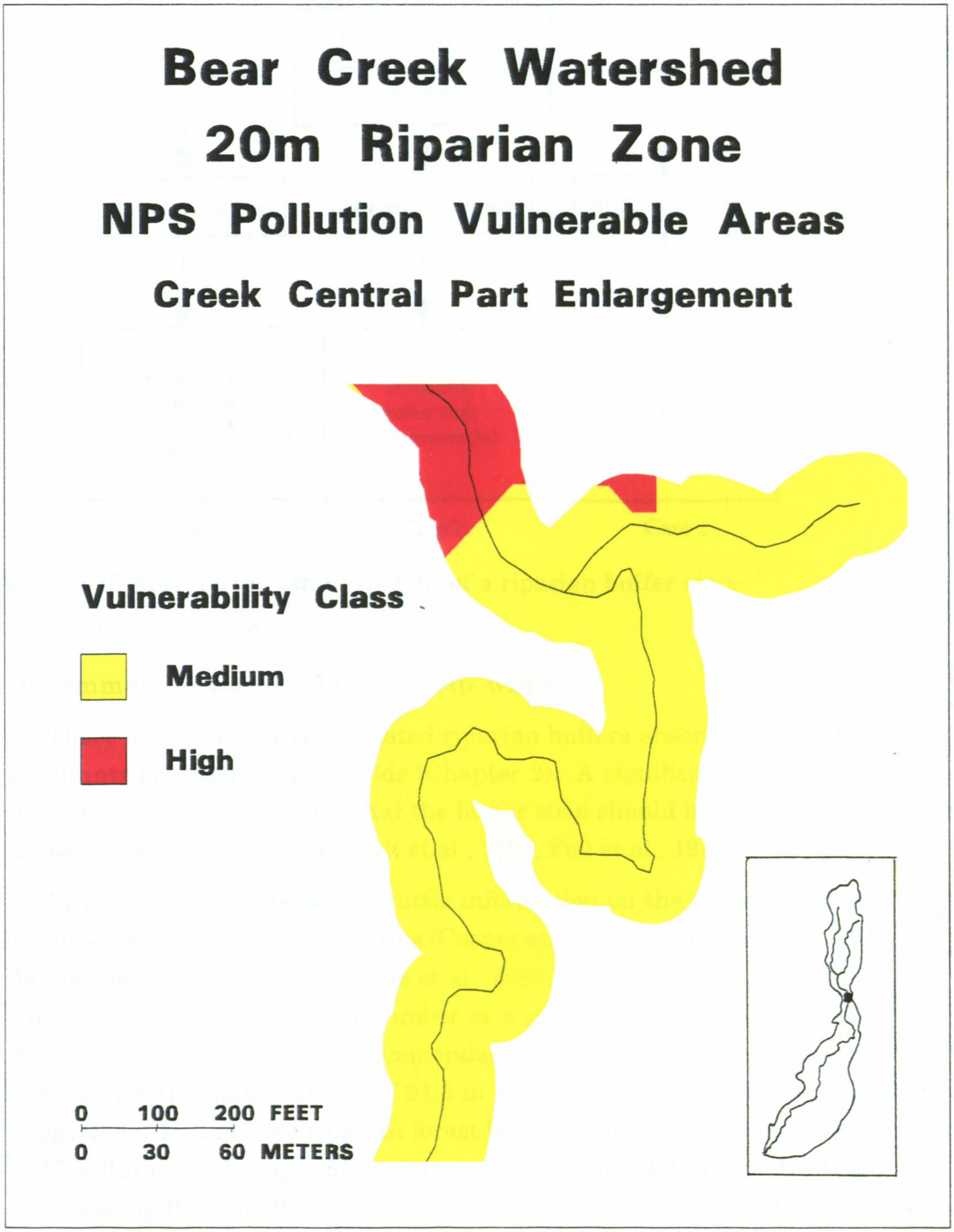


Figure 9. Bear Creek watershed riparian zone (20 m width) vulnerability map: central part of the creek enlargement

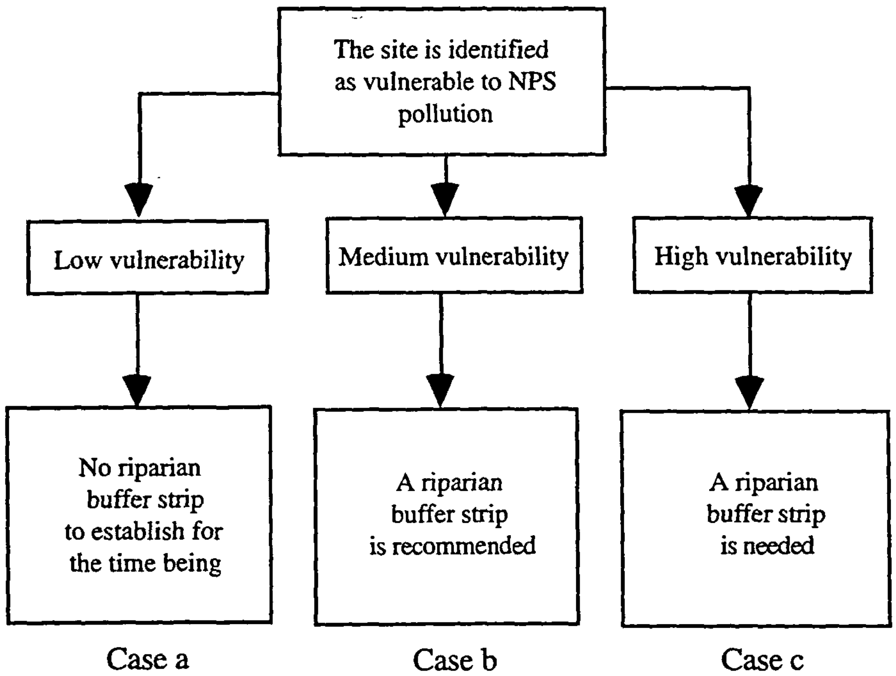


Figure 10. Key for the establishment of a riparian buffer strip

Recommendation of a buffer strip width

There is evidence that vegetated riparian buffers absorb agricultural pollutants lost from upland fields (Chapter 2). A significant issue associated with this ability is the width that the buffer strip should have in order to insure proper NPS pollution control (Belt et al., 1992; Fail et al., 1987).

Reviewing literature showed little information on the subject. Different studies used different buffer widths (Cooper et al., 1987; Dillaha et al., 1989; Jacobs and Gilliam, 1985; Magette et al., 1989; Peterjohn and Correll, 1984). There is no agreement over a number or a range of widths. For example, Agriculture Canada (1992) recommended the establishment of a grass buffer enhanced with wildlife shrubs of 91.5 m wide. Anderson and Masters (1992) suggested a 15.2 m wide riparian forest buffer is enough to filter the majority of NPS pollutants from agricultural activities. Bordeaux Continental Water Engineering Bureau (1992) has advised to leave a 3 m forested riparian buffer strip near cultivated fields. Welsch (1991) and the USDA Soil Conservation

Service (1993) have recommended a 29 m riparian buffer width. They are the only authors that describe a defined design for forested buffers. Total width is the sum of the width of three distinct zones. Zone 1 is a fixed 4.5 m strip composed of undisturbed trees planted at the top of the streambank. Zone 2 is a managed forest strip, occupying a maximum of 18.3 m. Zone 3 has a minimum width of 6.1 m and is made of grasses and/or forbs. The riparian buffer strip design in the Bear Creek project adapts well to these recommendations. The only difference is the combination of zones 1 and 2 into one zone.

Although authors do not reach a consensus on buffer strip width, there appears to be a lower limit of width below which effective removal of some pollutants may not occur. Experiments run with fescue filter strips by Magette et al. (1989) showed that greater pollution control is obtained with wider filter strips (9.2 m versus 4.6 m). In Virginia, it was found that a narrower filter strip length (4.6 m versus 9.1 m) reduced sediment trapping significantly (Dillaha et al., 1989). Three sets of plots were used. One plot in each set had no vegetative filter strip, another a 4.6 m one and the third a 9.1 m one. A 4.6 m orchardgrass filter strip was only able to prevent 86, 53 and 83% of the sediment from reaching the stream in the three plots, whereas a 9.1 m one showed results of sediment removal of 98, 70 and 93%. Therefore, buffer strip width really has an impact on effectiveness.

According to Smith M. (1992), the percent of slope and its length above the buffer zone are the only factors that influence the width of a filter because water from upland fields flows faster on a steeper slope. Riparian buffers below steep slopes thus need to be wider to be able to retain sediment. Longer slopes also have the potential to increase erosion, which augments the quantity of sediment. Smith M.'s recommendations for the width of filter strips related to soil slope were as shown in Table 7. They are rather narrow. According to these recommendations, minimum width of buffer strips in the Bear Creek watershed would be 4.6 m because most slopes are less than 9%. One demonstration in northeast Iowa, on both 7 and 12% slopes, measured more than 70% of the sediment from the field was removed within the first 3 m of a vegetative filter strip and more than 95% was removed within 9 m (Schultz et al., 1992). A survey of 18 farms in Virginia using vegetated filter strips also showed that filter performance depends on topography (Dillaha et al., 1989). In hilly areas, buffer strips were found to be ineffective for removing sediment and nutrients because of concentrated flow. Flatter areas had more uniform slopes and the filters were much more efficient.

Table 7. Guidelines for filter strip width related to slope (Smith M., 1992)

Field slope	Minimum width of filter strip
%	m
0-10	4.6
10-20	6.1
20-30	7.6

Anderson and Masters (1992) also argued that the width of an effective filter depends on the slope of the land adjacent to the stream. But they strongly related the width to the purpose of the buffer. For example, buffers need to be wider if the purpose is to manage for wildlife habitat. It has been found that the number of reptiles and amphibians is higher in wider streamside buffers (30 to 95.5 m compared to 0 to 25 m wide). One however needs to keep in mind such a suitable width will depend on the habitat requirements of the species considered of interest.

Although Welsch (1991) recommended a minimum buffer strip width of 29 m, he stated that the suitable width for a particular site depends on the soils. To him, the determination of such a minimum width can be based on soil hydrologic groups (Hydrologic group is the classification of a soil by the US Department Soil Conservation Service (SCS) according to its infiltration of water when it is completely wet and receives precipitation from long rains. Classes are A, B, C and D, ranging from a moderate to a very slow rate of infiltration). An increase in width is needed when riparian soils belong to C and D hydrologic groups. Welsch also suggested that width can be related to land capability class (SCS land capability class expresses the suitability of a soil for field crops. The classification is based on soil limitations for crops, risk of damage if cropped and the way the soil responds to management. There are 8 capability classes, ranging from low to severe erosion). The need for an increase in width when riparian soils have severe limitations that make them unsuitable for cultivation is as shown below.

Capability class	Total buffer width (Welsch, 1991)
I, II, V	29 m
III, IV	36.5 m
VI, VII	52 m

Although Welsch' s recommendations are for eastern forests naturally occuring along streams, it was interesting to see how they applied to the Bear Creek riparian zone. Figure 11 and Table 8 show the results of a land capability class analysis of the soils comprised in a 20 m width on both sides of the stream. For the most part, Bear Creek and its tributaries lie along capability classes II and V lands (55.8 km along class II and 12.2 km along capability class V). Class III riparian lands were also present but mostly on tributaries (5.4 km). The application of Welsch' s guidelines would indicate a 29 m width for most of the BCBS except for riparian zones in Class III requiring 36.5 m (these widths only pertain to areas previously identified as having a medium or high vulnerability: see Figure 10).

There may be times when the performance of a buffer strip can be greatly affected by rainstorms. Magette et al. (1989) have noticed a vegetative filter strip becomes less effective as more storm events occur. Dillaha et al. (1989) also pointed out efficiency can drop from 90 to 5% with inundation from storms. The problem with incorporating storm events into the buffer strip width determination is that we currently do not know enough about the role floods play in filter effectiveness (Phillips, 1989).
The debate could be whether to recommend a fixed width or a variable width (Belt et al., 1992). Laws can play a great role in this debate. The 1991 Streamside Management Law in Montana requires a 15.2 m minimum distance from a stream, lake or other water body (Logan and Clinch, 1991). Iowa does not have a riparian zone law. But in Idaho, for example, fixed

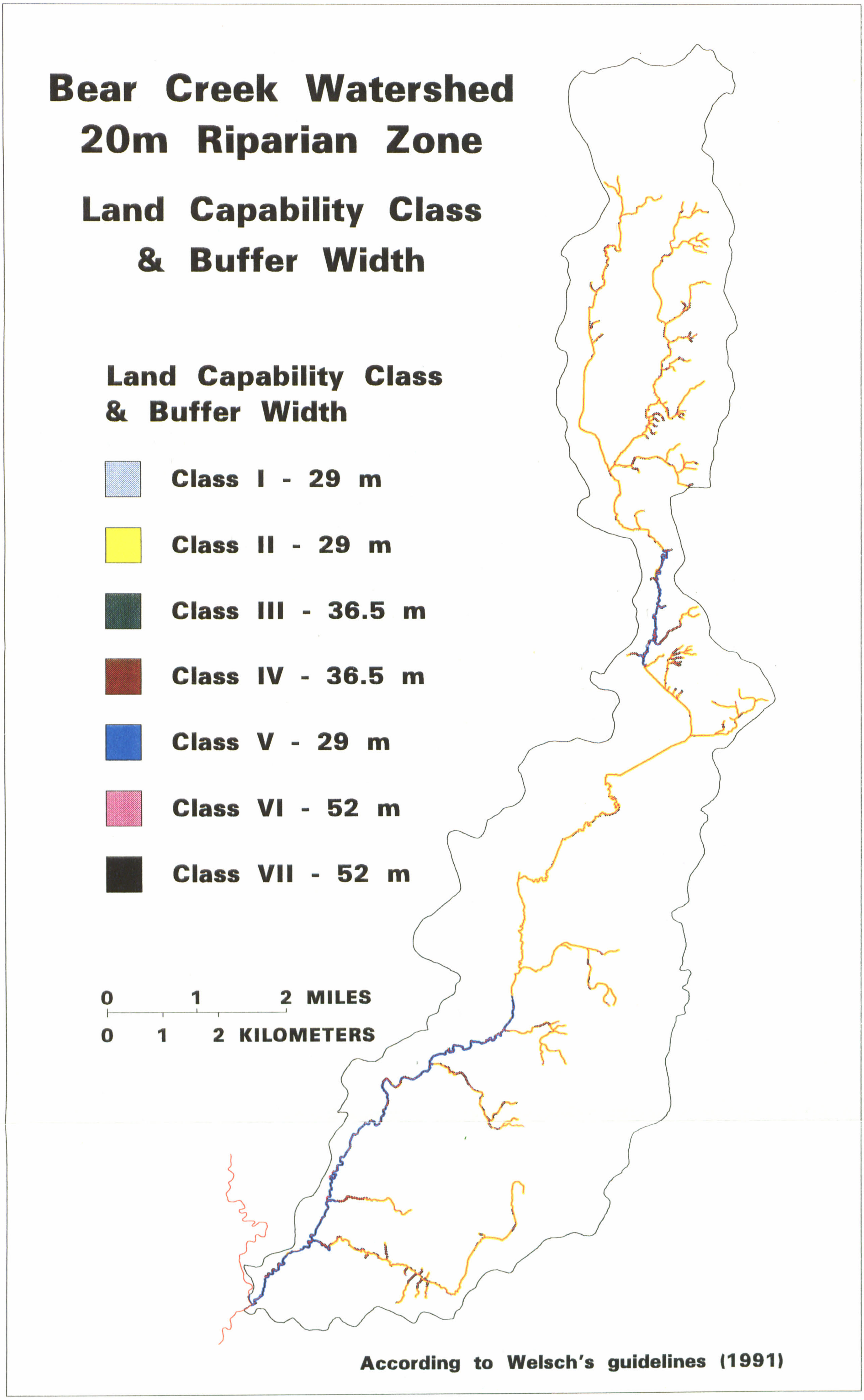


Figure 11. Bear Creek watershed riparian zone (20 m width): land capability class and buffer width

Table 8. Land capability class in the Bear Creek riparian zone (20 m width)

Capability class	Area (ha)	%Area*
I	7.7	2.1
II	257.9	71.5
III	34.0	9.4
IV	5.9	1.6
V	54.4	15.1
VI	0.3	0.1
VII	0.4	0.1

* Percent of total 20 m wide riparian zone.

minimum riparian buffer widths are imposed. They are determined by the intended water use. Soil stabilization practices are also required. Class I streams (drinking water and fish habitat) must have a width of 23 m. Class II streams (not for drinking water and not for fish production) must have a width of 1.5 m. No monitoring on their adequacy has however been carried on. In certain situations, such minimum widths may provide more protection than what is needed. The contrary may also be true. In that sense, it would appear that a variable width would be better suited because it would allow greater flexibility in each specific situation.

Variable buffer widths are being used in Oregon, California and Washington (Belt et al., 1992). Minimum widths are required by the law. They are then adapted to each particular case by taking into account factors like the stream width, the slope of the streambank and the land use. This determination is probably more appropriate to achieve particular protection goals. Anderson and Masters (1992) also pointed out that a buffer width depends on site conditions. According to them and Phillips (1989), all riparian forests are very different. Differences are in topography, percent slope and length, soil hydrological properties and vegetation composition. These differences are responsible for a variation in streamside zones' ability to control pollution. Since it is impractical to manipulate percent slope and soil hydrological properties, our only option for improving buffer strip effectiveness is to manipulate the width. Because of this natural wide range of effectiveness, it appears better to recommend not a single width, but a range of widths, each of them depending on particular site conditions. Maybe this is why no research has been able to come up with a specific width recommendation.

In the case of Bear Creek, a 20 m wide buffer strip is recommended. It is wider than some of the literature recommendations, though it does not meet the widths recommended by the Soil Conservation Service (1993) and Welsch (1991). Slopes are not steep in the Bear Creek watershed: 85.9% of the total watershed area has slopes less than or equal to 5%. In the 20 m riparian zone, 87.3% of the area has slopes less than or equal to 5% too. A wider filter length may not be needed. The overall flooding frequency in the area is not very high (5.34% of the area has a frequent or ponded frequency) (Figure 5 and Table 2), which does not call for an extremely wide buffer zone either. The application of Welsch' s guidelines however suggests the need to increase the 20m width in riparian zones with a land capability class of III. It is easy to modify the width because of the intrinsic design of the buffer, comprising three different vegetation type zones. For instance, if the landowner wants to emphasize timber production, the width of the strip of high quality trees can be expanded. In addition, 20 m corresponds roughly to the height of a mature tree, which means in case of windthrow, the adjacent cropland would not be damaged. Finally, a narrower strip would minimize the benefits to wildlife habitat enhancement. This aspect is important since it relates to another part of the overall Bear Creek project (Menzel and Schultz, 1992).

Knowing there is no agreement over the width of a buffer, we are nevertheless aware that choosing 20 m may not be the right choice. It may also not be the perfect width for all agricultural watershed situations, since it appears from reviewing literature that various factors can come into play for a buffer width decision. The identification of adequate criteria for determining width is difficult. One thing however seems to remain certain: the recommended width must increase with the intensity of disturbance of upland practices (Nutter and Gaskin, 1989).

In conclusion, there is no clear recommendation in literature about buffer strips' width. Different authors emphasize different factors deemed critical in the choice. There are no scientific means currently available to determine an optimal width. A flexible width appears better suited. One probably needs to know the site fairly well to take into account particular conditions like slope, upland use practices and vigor of the present or planned riparian vegetation to make a wise decision. More research on buffer strip width is obviously needed. But for now, the recommendation for the Bear Creek watershed is 20 m, although it is clear that the adequacy of this selection can not be proven.

Type of vegetation to establish on buffer strips

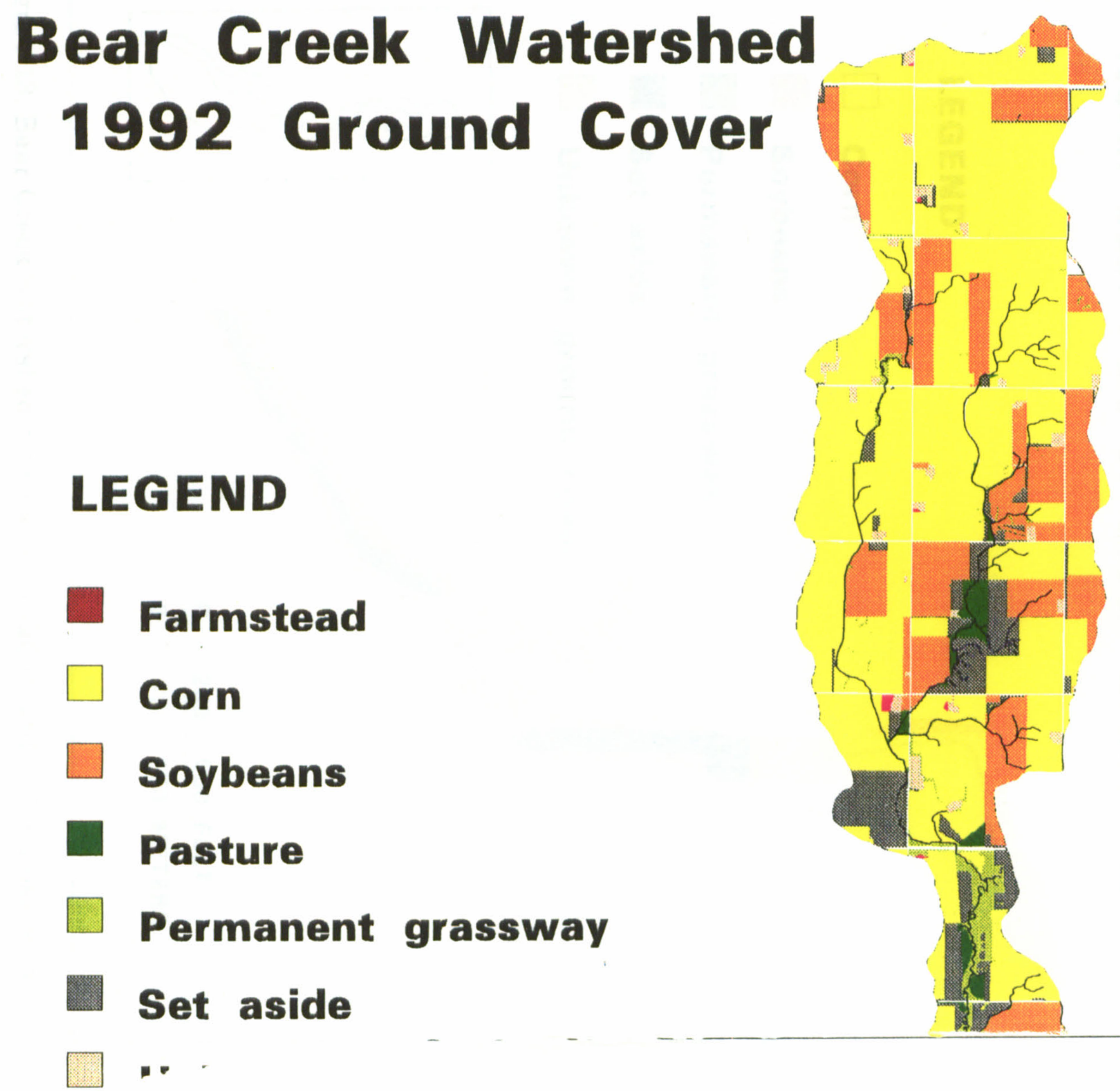
Functions of streamside vegetation

We have already seen that the value of riparian areas is directly related to the vegetation (Chapter 2). Vegetation improves water quality by filtering out sediment and nutrients from upland surface runoff and subsurface flow. It reduces soil erosion and helps to control flooding. A diversity of vegetation is utilized by a corresponding diversity of wildlife species. These species either use the riparian areas as permanent or seasonal homes, or as migration routes. Riparian vegetation also provides overhanging banks that shade the stream (Swanson, 1986). This shading affects nutrient availability in the water (Anderson and Masters, 1992). For instance, without shade, stream temperature increases about 15°C and larger P concentrations are present. Shading also shelters fish (Swanson, 1986). Fish require a high water quality with constant temperature and a high level of dissolved oxygen. The movement of water through the riparian vegetation can prevent eutrophication. In addition, vegetation contributes to streambank stability. If something happens that weakens the riparian vegetation, the stream may become wider and shallower. This is critical because it is deep and narrow streams that provide a good fish habitat. Wide and shallow streams do not provide such a favorable habitat because they catch more sunlight and have less dissolved oxygen. They result in less vegetation cover and a slower flow, which entails a higher concentration of pollutants.

Riparian vegetation thus plays a key role in the quality of stream water. In agricultural watersheds such as Bear Creek, we are often restoring streambanks and reestablishing vegetation on bare banks to get control of NPS pollution. It is therefore essential to have some knowledge of what species to plant on a particular site along a stream.

According to Bordeaux Continental Water Engineering Bureau (1988) and Sheeter and Claire (1989), the fact the stream flow speed is slowed down by the presence of riparian vegetation represents a tool to control streambank erosion. Oliver and Hinckley (1987) showed streamside forests can be manipulated to prevent erosion and altering of the stream channels. Management of the streamside forest canopy can be used to provide a favorable fish environment (Welsch, 1991). Vegetation cover manipulation also can be used to increase water yields by replacing high water demanding plant species by lower water-demanding ones (Debano and Schmidt, 1989). It thus appears possible to manipulate streamside vegetation to meet particular goals.

The goal in the Bear Creek project is to favor riparian vegetation that has the potential to mitigate NPS pollution. The predominant land use in the drainage basin is cultivation of corn and soybeans (Figure 12 and Table 9). Together, they represent more than 87% of the ground cover. When comparing the location of the vulnerable riparian areas with current management practices along the stream (Figure 13 and Table 10), it becomes apparent that the present vegetation, corn and soybeans on about 50% of the area and permanent grassways and set asides on 53% of the area, is inadequate. Cultivation near stream edges involves the use of heavy machinery that places excessive loads on the banks. This can cause slumping and increase erosion. With such practices, it is very likely that topsoil and pesticides will run off into the waterway. Some kind of perennial vegetation in the riparian zone is needed instead. Vegetation such as field corn or soybeans are annuals and present during 5 to 6 months of the year. The lack of cover for the other 6 to 7 months is not favorable for maintaining high soil infiltration rates, nor for trapping pollutants. The same is true with permanent grassways and set asides located in the 20 m zone that are planted in pasture grass. Pasture


Bear Creek Watershed
1992 Ground Cover
LEGEND
Farmstead
Corn
Soybeans
Pasture
Permanent grassway
Set aside

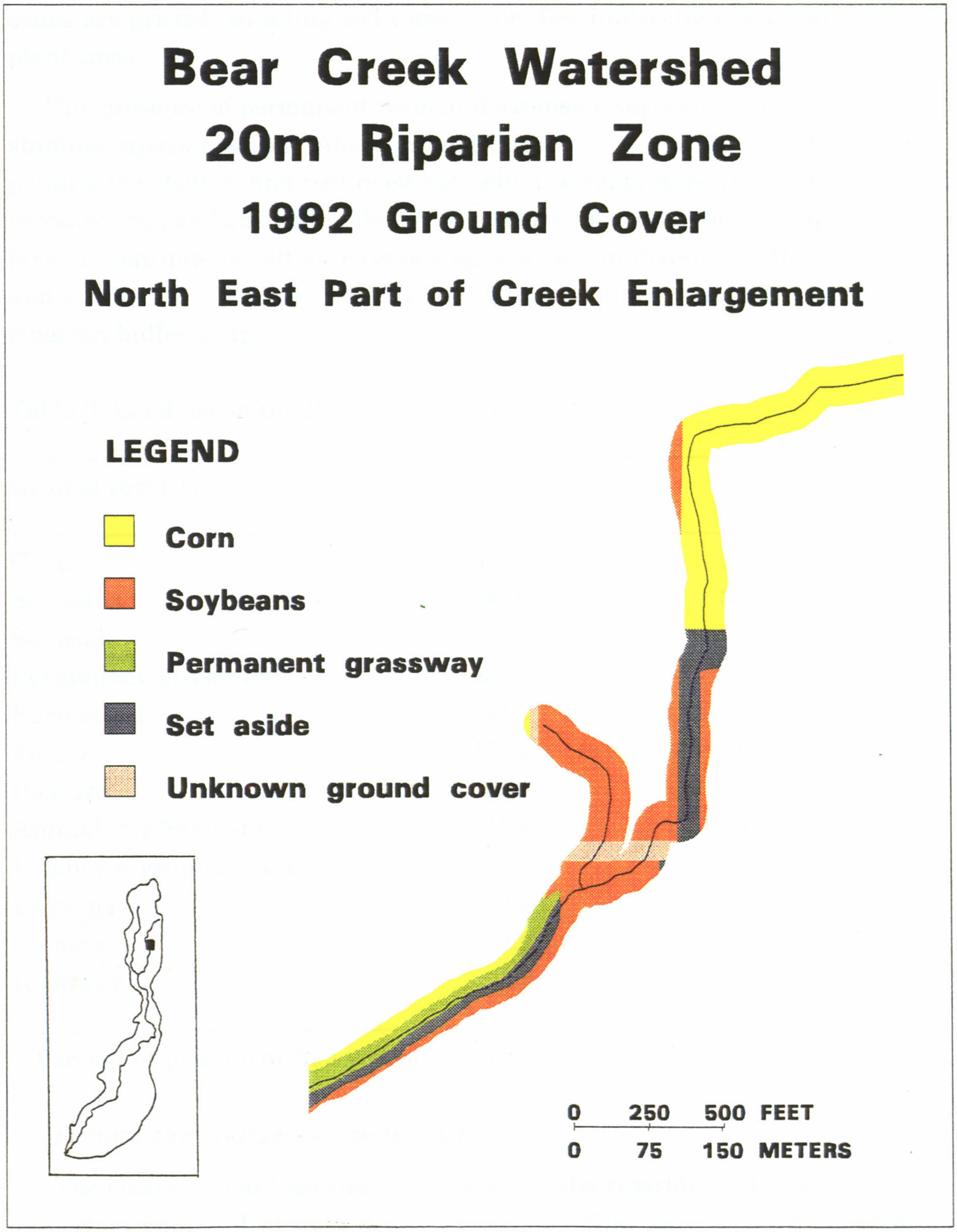


Figure 13. Bear Creek watershed riparian zone (20 m width) land use map: north east part of creek enlargement

zones are grazed, entailing soil compaction, low infiltration rates and minimal plant cover.

The presence of permanent roots and extensive vegetative cover helps stabilize riparian areas. Above-ground resistance to surface runoff containing pollutants is better, and root mass not only intercepts subsurface flow, but also increases streambank soil stability. Therefore, the recommendation is that farmers continue to cultivate cereals up to a certain distance to the stream, and modify their land use practices on the remaining strip of land: the 20 m riparian buffer strip.

Table 9. Land use in the Bear Creek watershed

Ground cover type	Area (ha)	%Area*
Corn	3885.6	55.6
Soybeans	2241.6	32.1
Set aside	353.8	5.1
Permanent grassway	164.1	2.3
Farmstead	121.6	1.7
Forest	100.2	1.4
Pasture	95.4	1.4
Animal confinement	11.8	0.2
Unknown ground cover	3.3	<0.1
Lagoons	3.1	<0.1
Cemetary	2.9	<0.1
Roadway	2.8	<0.1

* Percent of total identified ground cover area.

Factors that influence species selection

The choice of plant species to establish on the riparian buffer is an important point. Most work done on vegetated filter strips related in literature has been with forested riparian buffers. Besides a few rare cases of other types of vegetation (grass), a mixture of trees and grass or grass and shrubs (Agriculture Canada, 1992), and only two riparian forest buffer designs including trees, shrubs and grasses (USDA Soil Conservation Service, 1993; Welsch, 1991), it seems the idea of associating both shrubs and grasses with forest buffers has not been adopted. But the plan for the Bear Creek riparian buffer strips is to use trees, shrubs and grass. The structure of the buffer zone includes 5 rows of trees next to the stream, adjacent to 2 rows of shrubs and a strip of grass close to the agricultural field. As stated before (see Buffer strip width), this design is similar to those recommended by the USDA Soil Conservation Service (1993) and Welsch (1991).

Table 10. Riparian zone (20 m width) ground cover in the Bear Creek watershed

Ground cover type	Area (ha)	%Area*
Corn	101.1	33.0
Permanent grassway	68.8	22.4
Soybeans	47.2	15.4
Set aside	30.5	9.9
Forest	27.7	9.0
Pasture	25.4	8.3
Farmstead	2.4	0.8
Unknown ground cover	1.2	0.4
Lagoons	0.1	<0.1
Roadway	<0.1	<0.1

* Percent of total identified ground cover in the 20 m wide riparian zone.

It is an excellent idea to use a multiple species design for a riparian buffer zone. Even though trees should be the major component, adding shrubs and grasses can only enhance control over NPS pollution and reinforce streambank stability. An association of several different species brings a large diversity of above and below ground biomass distribution, which allows buffer zones to fulfill their role of trapping pollutants before they reach surface water or groundwater. In the Bear Creek buffer design, a prairie grass, switchgrass (*Panicum virgatum* L.), is used (IStART, 1993). It has dense stiff stems, which provide a large surface to intercept overland flow and causes sediment to drop in the riparian zone. Its extensive root system also produces a lot of organic matter that improves soil structure and water infiltration. As far as shrubs and trees are concerned, their perennial stems help reduce the speed of overland flow and flood flow as well. Their root systems are deeper than those of the prairie grass and include large diameter perennial roots. These contribute to soil and streambank stabilization.

A combination of trees, shrubs and grass thus has a high potential for filtering surface runoff and shallow groundwater flow within the root zone. This potential is greater than in a buffer with only one vegetation type. With the presence of multiple species, there is a diversity of nutrient uptake potential, which favors pollution buffering. Denitrification conditions that are necessary for N removal may be enhanced. Vegetation diversity also means better resistance to pests, diseases and climatic damages. A larger taxonomic diversity would not only be great for pollution control, but also for wildlife habitat diversity augmentation. It is important to point out that streamside areas are naturally characterized by a variety of plant species, adapted to a wide range of ecological conditions (Kauffman et al., 1985; Oliver and Hinckley, 1987). The existence of such a natural diversity reinforces the idea that multiple species buffer strips should be used in riparian zone restoration.

Another strategy in diversifying the vegetation cover would be to use unconventional crops as part of the riparian buffer. Current research on the ways to obtain energy from crops such as sweet sorghum or oilseed crops like peanut is not complete (Keeney and Deluca, 1992). Potential of such crops to filter sediment and nutrients has barely been studied (Young et al., 1980), as well as the feasibility of their establishment within riparian areas. The attracting aspect would be their potential economic value. The same is true for shrubs like hazelnut and riparian trees that could provide income from timber, firewood or biomass for energy.

Literature available on riparian vegetation focused only on describing and listing plant communities of streambanks in different regions, as well as investigating their ecology (Curry and Slater, 1986; Goodrich, 1991; Kauffman et al., 1985; Mason and MacDonald, 1990; Medina, 1986; Miller and Neiswender, 1987; Nillson, 1986). It is true our ability to successsfully restore and manage riparian areas will only improve as we gain a better understanding of what riparian communities are and what factors influence their existence and distribution. But for now, these lists and factors are of little help to give information on which type(s) of vegetation ought to be planted, so the riparian filter can remain in place and function properly to mitigate NPS pollution.

Information is also lacking on which species are most efficient at providing a better filter or a greater nutrient uptake, which could be useful in case of an extreme water quality problem. Literature on "what species to choose" is really lacking. The development in each state, in cooperation with different Natural Resources agencies, of suggested species lists for riparian vegetation adapted to particular areas would be helpful. Furthermore, literature on "how to restore" is scarce. Riparian management information which is available focuses only on grazing strategies in the southwestern US (Bezanson and Hughes, 1989; Elmore and Beschta, 1987; Thomas, 1986).

A few articles focus on the establishment and growth potential of a particular species (Sheeter and Claire, 1989; Svejcar et al., 1992). Some guidelines for the establishment of forest buffers have been developed in Pennsylvania (Welsch, 1991) and by the USDA Soil Conservation Service (1993). There is currently not enough information on how to rehabilitate or enhance riparian areas. If our common concern is to mitigate water pollution as much as possible, it is necessary to overcome these knowledge limitations. The main reason for such a lack of knowledge is the fact the valuable role of riparian systems has only been recently recognized (in the last 15 to 20 years). The number of studies conducted to date has not proved to be sufficient to provide riparian vegetation management data. Since riparian zones in each watershed have distinct characteristics, it also may be difficult to set up general guidelines.

When deciding on what riparian vegetation to establish, the idea of choosing native species must be considered. Gray et al. (1984) mentioned early Soil Conservation Service revegetation efforts in California used non-native species or plants although not in riparian zones. These plants were selected because of their availability and proven success in establishment. Emphasis has now moved towards the use of native species. USDA Soil Conservation Service (1993) and Welsch (1991) recommend using native species in their proposed riparian design. However, Smith M. (1992), who discussed the choice of riparian grass species, did not make this recommendation. The use of native or non-native species should be determined by the objectives of the riparian buffer strip. If the system is designed to maximize reduction of NPS pollution in the shortest time, then introduced species might be more efficient and quicker to establish. If specific products are desired by the landowner, introduced species might also be most suitable. However, native species are well adapted to the particular ecological characteristics of a riparian system and may be able to better withstand climate variations. If wildlife habitat and natural biodiversity are important, then native species should be used. When in doubt, native species should always be the first choice.

However, other factors not related to the riparian area itself can come into play and are important in the decision. Money limits the amount and diversity of revegetation efforts. The selection of species can be based on commercial or economic goals such as timber production. The availability of tree seedlings, shrubs, and/or grass seeds can have a significant impact. The time required for establishment, as well as the ease with which the vegetation types can be established are important aspects. One could also include wildlife or landscape considerations if they are part of the riparian area restoration project. Specific requirements of each wildlife species in question would need to be known. Finally, the focus may be to establish plants providing the greatest pollution control in a situation where there is a lot of inputs and little or no conservation practices upland.

In the BCBS model, the proposed vegetation cover is comprised mainly of native species. Silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), northern red oak (*Quercus rubra* L.), white oak

(*Quercus alba* L.), bur oak (*Quercus macrocarpa* L.), black walnut (*Juglans nigra* L.) and hackberry (*Celtis occidentalis* L.) are all native tree species in central Iowa (Barrett, 1980; Boon and Groe, 1990; Thompson, 1992). Willow (*Salix alba* X Si Matsudana) and cottonwood (*Populus* X *euramericana* 'Eugenei') species are hybrids that include one non-native parent. Besides nanking cherry (*Prunus tomentosa* Thunb.), shrub species selected: ninebark (*Physocarpus opulifolius* (L) Max.), chokecherry (*Prunus virginiana* L.), nannyberry (*Viburnum lentago* L.), silky dogwood (*Cornus obliqua* Raf.), and gray dogwood (*Cornus racemosa* Lam.) are also native. The same is true for the prairie grasses: switchgrass, yellow Indian grass (*Sorghastrum nutans* (L.) Nash) and big bluestem (*Andropogon gerardii* Vitman). This inclusion of native species in the Bear Creek project is very innovative.

Management considerations to maintain species effectiveness

A key issue is the maintenance of the riparian buffer strip because improperly functioning buffer is useless in reducing pollutant discharge into the stream. Disfunction would entail a loss of capacity for sediment removal and nutrient transformation and removal.

USDA Soil Conservation Service (1993) and Welsch (1991) stress the importance of forbidding any kind of traffic within the riparian zone as well as avoiding excess use of pesticides. According to Anderson and Masters (1992), it is important to prevent overgrazing. A regular inspection for sediment build-up is required (Smith, 1992; Welsch, 1991). This is due to the fact that soil can build up along the edge of the buffer strip as sediment loads are deposited. If deemed necessary, reseeding of the grass strip can be done to maintain vegetation density. Welsch (1991) and Agriculture Canada (1992) recommend harvesting and removing the grass.

As trees mature, annual nutrient uptake diminishes. This means trees in the riparian buffer strip might not be long-term filters. But with a selective harvesting practice, they can remain in an active growth phase (Anderson and Masters, 1992; Fail et al., 1987; Lowrance et al., 1985; Lowrance et al., 1984b). Young trees will replace old ones - nutrients stored in woody biomass will then be removed - and vigorous nutrient uptake will be maintained. Anderson and

Masters (1992) stress the fact that BMP's need to be used when harvesting trees to avoid disturbance of the riparian zone. Welsch (1991) cautions that besides this periodic cutting, trees and shrubs must be left undisturbed. Maintenance could also include establishing new seedlings if needed or favoring natural regeneration.

In an agriculturally dominated watershed, chances are great the streamside land will belong to farmers for the most part. Before having them maintain a riparian buffer, one has to realize farmers are not silviculturists. In other words, they will not be able to carry out the proper maintenance of the filter strip without some forestry technical assistance. In particular, this kind of help will be needed if their goal is to derive income from fuel wood or timber from the riparian buffer.

The long-term maintenance of the vegetated riparian zone is also closely related to upland agricultural practices (Anderson and Masters, 1992). Since an overloading of sediment can alter the filtering capacity (Smith M., 1992), it is important to keep pollutant loadings down to levels that can be processed properly by the riparian zone. For nutrient management and erosion/sediment control, riparian buffer strips have to be combined with upland agricultural BMP's like no-till, reduced pesticide application, etc... A riparian buffer can only act as a final line of defense and can not replace soil conservation practices in the fields above it. The socio-economic survey done in the Bear Creek watershed (Menzel and Schultz, 1993) indicated a trend among farmers to resort to soil conservation practices (contour farming, terraces, no-till etc.), which may represent an asset in the future.

Research work mentioned that nutrient removal by the riparian zone is negatively affected by the presence of drainage tiles (Jacobs and Gilliam, 1985). Tiles are present in numerous locations in the watershed below the riparian zone at 0.5 m to 2 m deep. This could be an obstacle to the establishment of the multispecies riparian vegetation because tree roots may interfere with the tiles by clogging them. Prior to installation of the riparian vegetation, tiles below the 20 m wide buffer zone should be replaced by non-perforated tiles to avoid root clogging of the holes (IStART, 1993).

In conclusion, the choice of what riparian vegetation to establish is an extremely important consideration. Guidelines for selecting species are presently limited. The potential represented by a multispecies design has not been explored to date. The Bear Creek project represents a unique multispecies design using native and non-native species to mitigate NPS pollution, providing streambank stability, economic products for the landowner as well as diverse wildlife habitat.

Bear Creek riparian vegetation cover

Observations and results collected from research on BCBS have identified useful elements for the possible future establishment of buffer strips in the watershed (IStART, 1993). Recommendations on plant species have been made, although numerous species could be used. To assist in future matching species to BCBS sites and contribute to their successful establishment, a set of selection criteria should be established.

The layout of a multispecies buffer strip for the riparian zone, as recommended by IStART (1993), is composed of 5 rows of trees on the first 10 m of the streambank, 2 rows of shrubs on the next 4 m, and a 6 m strip of grass adjacent to the crop field. This model is for a 20 m buffer strip but can easily be adapted for a wider or narrower width. The riparian management system also includes willows in the streambank and in the stream, wherever there is a serious potential for bank erosion (medium and high risk). Since 50% of stream sedimentation may come from bank collapse, this is an important practice. Among the 5 rows of trees, the first 3 or 4 are devoted to biomass production and the other 1 or 2 to timber production. Tree species recommended for biomass production (fast growing species) are willow, cottonwood and silver maple. Tree species planned for timber production (slower growing species) are green ash, white oak, bur oak, northern red oak, black walnut and hackberry. Shrub species chosen are ninebark, chokecherry, nannyberry, silky dogwood, nanking cherry and gray dogwood. For the grass strip, switchgrass plus mixtures of yellow Indian grass and big bluestem are recommended.

The planting layout of a buffer strip will differ depending on its location on the north side or the south side of the stream. Shading of slower growing high quality tree species may occur if fast growing species are planted on the south side of these trees. As a result, a north side buffer strip layout will only include fast-growing biomass tree species, whereas high quality trees can be grown in the southern 1 to 2 rows on the south side. On sites oriented east or west, it is possible to establish a design similar to a south side one, since problems of shading would not be as detrimental.

Guide to species selection

The following presents a practical guide for the establishment of vegetation on sites corresponding to cases b and c found in the BCBS establishment key (Figure 10). A decision model has been developed based on soil information critical for plant establishment and on important ecological characteristics of each species (Figures 14, 15 and 16). The key is divided into a soils table, species tables and a vegetation selection decision model.

The first table (Table 11) sums up important characteristics of the Bear Creek watershed soils. Data was obtained from the soil surveys of Story County and Hamilton County (DeWitt, 1984; Dideriksen, 1986). The characteristics that are included in Table 11 were selected because of their pedological and silvicultural importance. Numerous other criteria could have been chosen. These were, however, judged as most relevant for the vegetation selection decision model.

The Bear Creek watershed soils have been identified by series. The following characteristics are presented:

1. Surface texture - The texture corresponds to the one of a typical pedon of the series. Texture is important for the plant root growth and uptake of water and nutrients.
2. pH of A horizon - The pH is an average for the A horizon. This horizon is the first one encountered during plant growth. Most of the fine feeder roots of trees are located in this horizon. According to Kimmins (1987), all fine feeding roots are concentrated in the upper cm of the soil, even if the root system goes as deep as 2 m or more. The pH is also directly

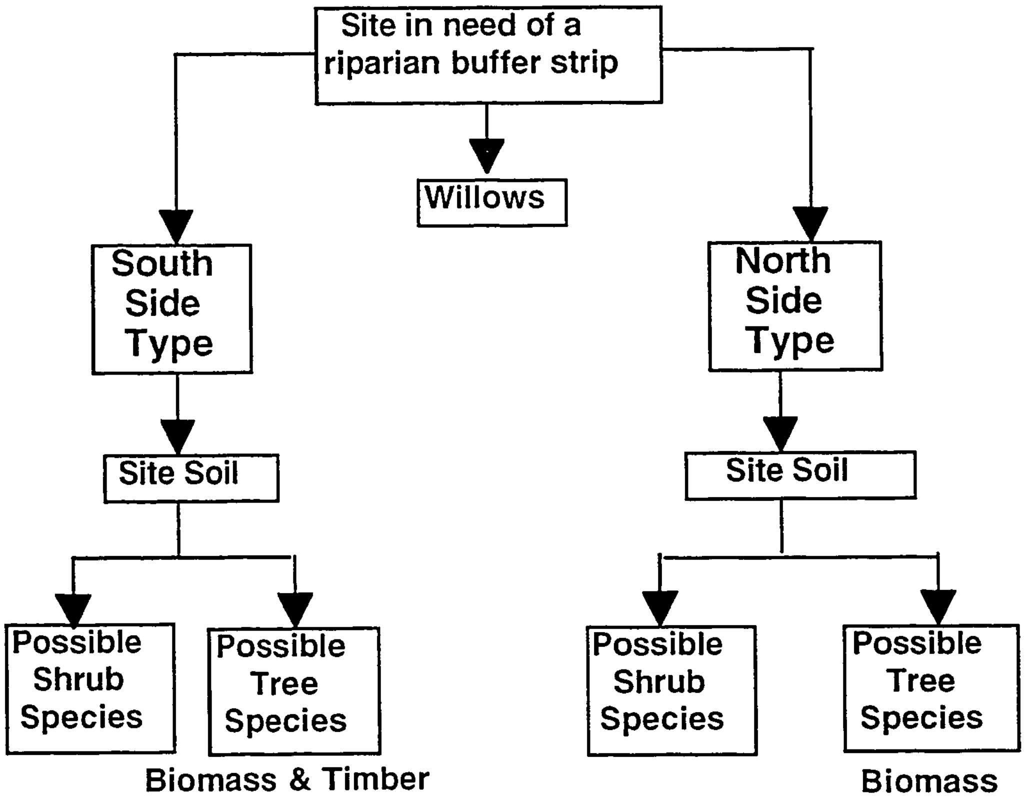


Figure 14. First part of the vegetation selection model rationale

related to the quantity of nutrients present. In that sense, it is an indicator of the soil fertility and of the potential growth of the tree or shrub.

3. Depth to high water table - The depth to the high water table is the seasonal highest level that the saturated zone in the soil can reach. For the Bear Creek soils, this happens during a portion of the growing season (November to June on average). A high water table is crucial for plant growth because it can affect the tree or shrub when it is newly planted and when it is growing (root development). A high water table depth determines the amount of "water-free" soil that can be explored by the roots: it is thus a limiting factor in root system development.
4. Available water capacity - Soil moisture has been quantified as the available water capacity. It refers to the quantity of water that the soil is capable of storing for use by plants. It corresponds to the difference between

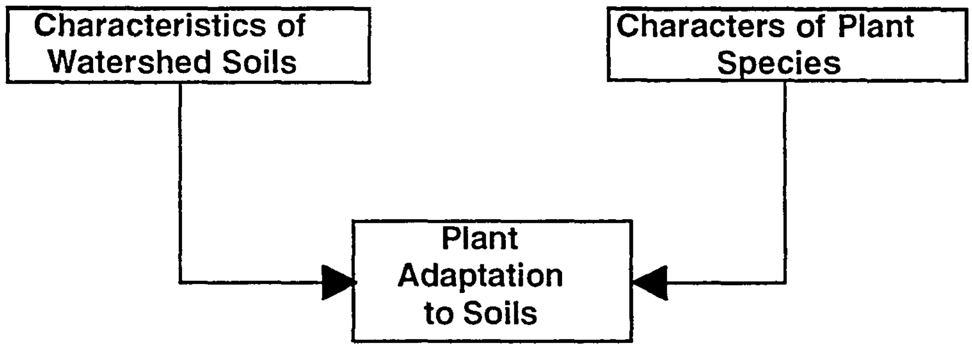


Figure 15. Determination of plant adaptation to soils

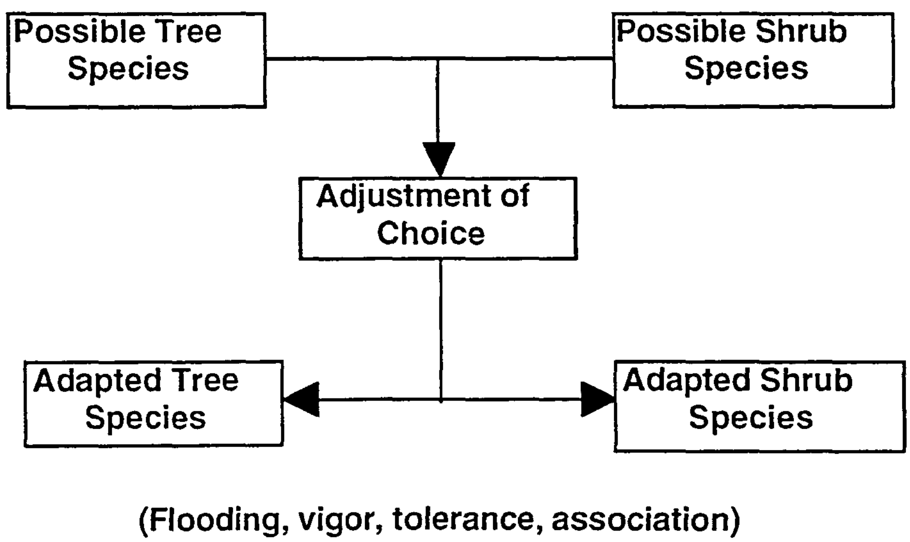


Figure 16. Second part of the vegetation selection model rationale

Table 11. Important characteristics of the Bear Creek watershed soils

Soil Series Name and Mapping Unit[a]	Number	Surface Typical Texture	pH of A Horizon	Depth to High Water Table (cm)	Moisture (AWC)[b]	Drainage Class	Thickness of A Horizon (cm)	Depth to Free Carbonates (cm)
Biscay (259)	1	Clay loam	6.95	30-90	M	Poorly drained	40	81-102
Canisteo (507)	2	Clay loam	7.9	30-90	H	Poorly drained	58	25-51
Clarion (138B)	3	Loam	6.45	> 180	H	Well drained	33	46-127
Clarion-Storden loams (638C2)	4	Loam	6.7	> 180	H	Well drained	21	In all horizons
Coland (135)	5	Clay loam	6.7	30-90	VH	Poorly drained	120	—
Coland-Terril complex (201B)	6	Clay loam	6.7	30-90	H	Poorly drained	81	—
Cylinder (202)	7	Loam	6.45	60-120	M	Somewhat poorly drained	33	102
Dickinson (175)	8	Fine sandy loam	6.45	> 180	L	Somewhat excessively drained	43	—
Estherville (34C)	9	Sandy loam	6.45	> 180	L	Somewhat excessively drained	23	38-76
Farrar (253B)	10	Fine sandy loam	6.45	> 180	H	Well drained	36	61-102
Flager (284)	11	Sandy loam	6.45	> 180	L	Somewhat excessively drained	53	> 152
Hanlon-Spillville complex, channeled (1314)	12	Loam	6.67	90-152	H	Moderately well drained to somewhat poorly drained	99	122
Harps (95)	13	Loam	8.15	30-90	H	Poorly drained	51	In all horizons
Harps-Okoboji complex (956)	14	Loam	7.67	+ 30-30	H	Very poorly drained	51	In all horizons

Table 11. (continued)

Soil Series Name and Mapping Unit[a]	Number	Surface Typical Texture	pH of A Horizon	Depth to High Water Table (cm)	Moisture (AWC)[b]	Drainage Class	Thickness of A Horizon (cm)	Depth to Free Carbonates (cm)
Hayden (168B)	15	Loam	6.45	> 180	M	Well drained	20	61-152
Knoke (4)	16	Silty clay loam	7.9	+ 30-30	H	Very poorly drained	81	In all horizons
Lester (236B)	17	Loam	6.05	180	H	Well drained	28	51-137
Nicollet (55)	18	Loam	6.45	75-150	H	Somewhat poorly drained	43	51-122
Okoboji (6)	19	Silty clay loam	7.2	+ 30-30	VH	Very poorly drained	81	51-127
Rolfe (274)	20	Silt loam	6.2	+ 30-30	H	Very poorly drained	48	107-152
Sparta (41B)	21	Loamy fine sand	6.2	> 180	L	Excessively drained	40	—
Spillville (485)	22	Loam	6.45	90-152	H	Moderately well drained to somewhat poorly drained	152	—
Spillville-Coland complex, channeled (1585)	23	Loam	6.57	30-90	VH	Poorly drained	120	—
Storden (62C3)	24	Loam	7.9	> 180	H	Well drained	20	In all horizons
Storden-Hayden loams (356G)	25	Loam	7.3	> 180	H	Well drained	20	In all horizons
Talcot (559)	26	Clay loam	7.9	30-75	M	Poorly drained	48	In all horizons
Terril (27B)	27	Loam	6.7	> 180	H	Moderately well drained	81	—

Table 11. (continued)

Soil Series Name and Mapping Unit[a]	Number	Surface Typical Texture	pH of A Horizon	Depth to High Water Table (cm)	Moisture (AWC)[b]	Drainage Class	Thickness of A Horizon (cm)	Depth to Free Carbonates (cm)
Wacousta (506)	28	Silty clay loam	6.95	+ 30-30	VH	Very poorly drained	33	30-51
Wadena (108)	29	Loam	6.45	>180	L	Well drained	31	112
Waukee variant (1178)	30	Loam	5.8	>180	VH	Well drained	56	>= 180
Webster (107)	31	Clay loam	6.95	30-60	H	Poorly drained	43	61-102
Zenor (828B)	32	Sandy loam	6.45	> 180	M	Somewhat excessively drained	28	51-102

[a] Orthent loamy, Aquents loamy reclamation and pits, sand and gravel — that are part of the Bear Creek watershed soils — were not included in the table because of the great variability of these materials and their disturbance by man.

[b] AWC stands for Available Water Capacity. It was expressed as follows:
L (low) ....7.5 to 15 cm
M (moderate).........................15 to 22.5 cm
H (high)...............................22.5 to 30 cm
VH (very high)......................> 30 cm.

the amount of soil water at field moisture capacity and the amount at wilting point. It is expressed for a 1.52 m profile. It was necessary to consider the whole profile because moisture is taken up by the tree throughout the whole profile wherever it is available to roots.

5. Drainage class - Drainage class refers to the frequency and duration of soil saturation. It provides an indication of soil infiltration rates and potential for root aeration and respiration.
6. Thickness of A horizon - The thickness of the A horizon has been included because of the particular importance of that layer as explained above with soil pH. Kimmins (1987) indicates nutrient uptake occurs in fine roots and mentions they tend to be concentrated in the surface soil. The A horizon therefore influences buffer vegetation establishment success.
7. Depth to free carbonates - The depth to free carbonates has also been included because it can be a severe limiting factor for the growth of some tree species that cannot stand carbonates in the soil. The presence of calcium carbonates in the soil results in a saturation of the clay-humus complex with calcium cations. Cations necessary for the proper growth of the tree are then no longer available. It is thus useful to know about the depth to free carbonates.

As a recap, all criteria for the characterization of the Bear Creek soils have been chosen according to their influence on the decision of which tree and shrub species to establish on the riparian buffer strips. Texture and pH reflect the quantity of nutrients available for plant growth. Texture, high water table depth, moisture and drainage class influence how the tree or shrub will be able to take up water, how root respiration will occur and how well the plant will be anchored - which further tells about resistance to wind and flooding.

Overall, the Bear Creek watershed soils have a dominant texture of loam or clay loam. The pH is generally close to neutral, with values ranging from 6 to 8. Fifteen soils have a water table that can rise to within 30 cm of the soil surface. Six of these soils have an apparent water table (thick zone of free water in the soil) and are very poorly drained. In general, all soils have a lot of moisture (the very high or high code prevails). Sixteen soils are well drained to somewhat excessively drained, which denotes a wide range of soils, influencing the type of vegetation to plant. Apart from 7, all soils in the basin have free carbonates in their profile, including some over the whole profile.

The second table (Table 12) sums up some important ecological characteristics of the tree species recommended for the BCBS by IStART (1993). Information for each species includes the soil requirements, the root system, the tolerance to competition, the species the tree can be associated with, the resistance to different damaging agents and some particular requirements. All data was obtained from the literature (Barrett, 1980; Bercovici F., 1991; Bercovici M., 1990; Boon and Groe, 1990; Burns and Honkala, 1990; Dirr, 1983; Hightshoe, 1988; IDF, 1990; Preston, 1989; Rameau et al., 1989; Sargent, 1933; Schuyler, 1915; Thompson, 1992; Van der Linden and Farrar, 1984). The Bear Creek watershed soils the species can grow on was determined thereafter.

Data on soil requirements matches the pedology characteristics of the soils in Table 11. Other data is as follows.

- Thickness of the A horizon and depth to free carbonates were taken into account when species had a specific requirement.
- Growth rate is an important characteristic because it plays a role in the choice of the location of the species in the buffer design.
- Information on the root system indicates the possibility for roots to penetrate through the soil to absorb nutrients and water. The type of root system is linked to the trees tolerance to a high water table. It can also reflect the ability of the tree to resist drought. Finally, it is directly related to how well the tree is anchored and resists wind and storms.
- Data on tolerance to competition and on the species the tree can be associated with (forest cover) are useful for deciding on the layout of the species in the buffer strip.
- Susceptibility to periodic flooding, climatic agents and damaging agents are helpful to achieve the aim of establishing an efficient buffer.
- Comments include any particular requirement of the species.
- Finally, the column showing the Bear Creek soils that the species are adapted to represents an important component in the selection of plant cover to establish. This column was developed in the following way. Considering

Table 12. Main silvical characters of the tree species recommended for the Bear Creek watershed buffer strips

Species	Soil Requirements					Growth Rate	Rooting Habit	Tolerance to Competition	Associated Species	Susceptibility			Comments	Possible Suitable Soils (% soils)[i]
	Typical Texture[a]	pH[b]	Depth to High water Table [c]	Moisture[d]	Drainage Class[e]					Periodic Flooding[f]	Climatic Agents[g]	Damaging Agents[h]		
Willow	N	6.5 to 7.5	Superficial	VD	VP–P	Very fast	– Shallow rooted – Dense root system	Very intolerant	– Pure stands – Cottonwood	No	W	I	Easy vegetative multiplication	1, 2, 4, 5, 6, 7, 12, 13, 14, 16, 18, 19, 20, 22, 23, 25, 26, 27, 28, 31 (62.5%)
Poplar hybrid	FSL to SIL	6 to 7	Deep	VD	W	Very fast	Strong horizontal surface roots with plunging roots	Very intolerant	– Pure stands – Willow, bur oak, green ash, hackberry	– Young tree: plantation; long – Mature tree: April-September; long	W	A-I	Seedlings are affected by grass, weed and shrub competition during the first 2 years	3, 4, 8, 9, 10, 11, 12, 15, 17, 18, 20, 22, 23, 24, 25, 27, 29, 30, 32 (59.5%)
Silver maple	SAL to SIC	5.5 to 6.5	Somewhat deep	VD	P to W	Very fast	Shallow, prolific root system	Intermediate	Cottonwood, willow, green ash, bur oak, red osier dogwood	– Mature tree: April-September; long	SW	N	Seedlings are affected by overtopping vegetation	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 17, 18, 20, 22, 23, 24, 25, 27, 29, 30, 31 (72%)
Green ash	S to SIL–CL	6.5 to 7.5	Somewhat deep	VD	W	Fast	Extensive heartroot system	Intolerant	Cottonwood, willow, silver maple, bur oak, northern red oak, hackberry, quaking aspen	– Mature tree: April-May; 2 months	C	A–I	– Seedlings are affected by weed competition – Chlorosis on soils with pH >= 8	3, 4, 5, 6, 10, 12, 15, 17, 18, 22, 23, 24, 25, 27, 29, 30, 31, 32 (56%)
Northern red oak	LS–L–SIL–CL–SICL	4.8 to 6.5	Deep	ND	W	Moderately fast	Extensive deep root system	Intermediate	Green ash, white oak, bur oak, black walnut, hackberry, quaking aspen, nannyberry	– Young tree: any – Mature tree: any	S	I-D	- Does not stand free carbonates in the soil except if deeply located - Needs a thick A horizon	3, 7, 8, 10, 11, 12, 15, 17, 18, 20, 21, 22, 23, 27, 29, 30, 32 (53%)
White oak	SAL–L	5.5 to 6.5	Very deep	D	W–E	Slow	– Deep root system – Taproot replaced with age by a heartroot system	Intermediate	Oaks, hickories	– Young tree: any – Mature tree: any	SW	I-D	– Grows best on low slopes – Mineral nutrition is not limiting	3, 4, 7, 8, 9, 10, 11, 15, 17, 18, 21, 22, 24, 25, 27, 29, 30, 32 (56%)
Bur oak	S to CL	4.6 to 8	Extremely deep	U	W	Slow	– Extensive deep root system – Taproot replaced with age by a heartroot system	Intermediate	Silver maple, cottonwood, green ash, northern red oak, white oak, quaking aspen, red osier dogwood	– Young tree: any – Mature tree: any	N	I-D	– Often associated with calcareous soils – Can compete successfully with prairie grasses -- Resistant to drought	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30, 31, 32 (87.5%)

Table 12. (continued)

Species	Soil Requirements					Growth Rate	Rooting Habit	Tolerance to Competition	Associated Species	Susceptibility			Comments	Possible Suitable Soils (% soils)[i]
	Typical Texture[a]	pH[b]	Depth to High water Table [c]	Moisture[d]	Drainage Class[e]					Periodic Flooding[f]	Climatic Agents[g]	Damaging Agents[h]		
Black walnut	SAL–L–SIL–SICL	5.5 to 7.5	Deep	VD	W	Fast	– Deep widespread root system – Large taproot	Intolerant	Oaks, hackberry, hickories, silver maple, green ash	– Young tree: plantation; short Mature tree: April-June; 3 months	C	A–I–D	– Root collar must not be buried – Seedlings require weed control for the first 3 years – The soil must not have free carbonates in the upper layer	3, 9, 10, 11, 12, 15, 17, 18, 20, 22, 23, 27, 29, 30, 32 (47%)
Hackberry	SAL-L-SIL	6 to 8	Deep	U	W	Moderately fast	– Deep root system – Occasional taproot	Intermediate	Green ash, silver maple, black walnut, eastern wahoo	– Young tree: plantation; 2 months	N	I–D	– Mature tree is drought resistant	3, 4, 7, 8, 9, 10, 11, 12, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 27, 29, 30, 32 (69%)

[a] The texture tolerated by the tree can be:
S .... sand
LS .... loamy sand
FSL .... fine sandy loam
SAL .... sandy loam
L .... loam
SIL .... silt loam
S .... silt
CL .... clay loam
SICL .... silty clay loam
SIC .... silty clay
C .... clay
N .... no particular texture.

[b] The soil pH required by the tree is either the number or range of number given, or any pH (N).

[c] The following classes have been defined:
Superficial water table .... 30-60 cm
Somewhat deep water table .... 60-90 cm
Deep water table .... 90-120 cm
Very deep water table .... 120-150 cm
Extremely deep water table .... > 150 cm.

[d] A correspondence has been established between the soil moisture requirements of the tree and the Available Water Capacity level of the soil (Table 11):
The tree is: very demanding (VD) .... H, VH soil moisture required
demanding (D) .... M soil moisture needed at least
not demanding (ND) .... L soil moisture needed at least
unaffected (U) .... any soil moisture can fit.

[e] The species – withstands a very poorly drained soil: VP
(very poorly drained in Table 11)
– withstands a poorly drained soil: P
(poorly drained; somewhat poorly drained, in Table 11)
– needs a well drained soil: W
(moderately well drained; well drained, in Table 11)
– needs an excessively drained soil: E
(somewhat excessively drained; excessively drained in Table 11).

[f] The tree is susceptible to periodic flooding: – in the young age: period; duration
– as a mature tree: period; duration

The tree is not susceptible to periodic flooding: Nc.

[g] The tree can be injured by snow and/or ice .... S
The tree can be injured by the wind .... W
The tree can be injured by the cold and/or frost C
The tree shows no major susceptibility .... N

[h] The tree can be seriously damaged by animals .... A
The tree can be seriously damaged by insects I
The tree can be seriously damaged by diverse diseases .... D
There are no significant damages by animals, insects or diseases .... N

[i] The possible suitable soils are listed by their number in Table 11. The % soils indicated is equal to the number of soils to which the species is adapted divided by the total number of soils.

the species ecological characteristics, the 36 Bear Creek soils were analysed to establish a correlation between these ecological features and the characteristics of each soil. It was therefore possible to determine whether a species was adapted to a soil or not. The criteria of depth to free carbonates was considered decisive. On the assumption that the 5 soil requirement criteria of Table 11 were all equally important (same weight) for the survival, growth and functioning of the tree species, the adaptation of a species to a soil was judged possible when at least 3 criteria were met.

Table 12 shows a great variability of ecological characters among the species. Table 13 is a recapitulation of the tree species adapted to each soil and allows to distinguish species having a similar ecological range in the Bear Creek watershed, based on the number of soils they are adapted to:
- species having a large ecological range (>60%): bur oak, silver maple, hackberry and willow;
- species having a medium ecological range (50-60%): cottonwood, green ash, white oak and northern red oak;
- species having a small ecological range (< 50%): black walnut.

As far as soils are concerned, Nicollet, Spillville and Terril can be planted with any of the tree species. Soils suitable to only 1 species are Knoke, Okoboji and Wacousta. Soils suitable to 2 to 3 species are Biscay, Canisteo, Harps, Harps-Okoboji complex and Talcot. Clarion, Canisteo, Harps, Nicollet and Webster represent 78% of the Bear Creek basin surface. Among these 5 soils, only Canisteo and Harps are restricted to a small number of suitable tree species.

Table 14, dealing with the shrub species recommended for the BCBS by IStART (1993), is similar to Table 12 and has the same objectives. For each shrub species, a number of characteristics were collected in literature (Boon and Groe, 1990; Dirr, 1983; Hightshoe, 1988; Hortline, 1994; Ingram, 1948; Schuyler, 1915; Snyder, 1987; Van der Linden and Farrar, 1984).

Species soil requirements help to identify soils to which the species can adapt. Growth rate is an indication of shrub vigor during buffer strip establishment. Tolerance to competition is helpful for the buffer strip shrub

Table 13. Recapitulation of the tree species adapted to the Bear Creek watershed soils

Soil Mapping Unit[a] / Species	259	507	138B	638C2	135	201B	202	175	34C	253B	284	1314	95	956	1688	4	2368	55	6	274	41B	485	1585	62C3	356G	559	27B	506	108	1178	107	828B
Bur oak	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X		X	X	X	X	X	X	X	X		X	X	X	X
Silver maple		X	X	X	X	X	X		X	X	X	X	X		X		X	X		X		X	X	X	X		X		X	X	X	
Hackberry			X	X			X	X	X	X	X	X		X	X		X	X		X	X	X	X	X	X		X		X	X		X
Willow	X	X		X	X	X	X					X	X	X		X		X	X	X		X	X		X	X	X	X			X	
Poplar hybrid			X	X				X	X	X	X	X			X		X	X		X		X	X	X	X		X		X	X		X
Green ash			X	X	X	X				X		X			X		X	X				X	X	X	X		X		X	X	X	X
White oak			X	X			X	X	X	X	X				X		X	X			X	X		X	X		X		X	X		X
Northern red oak			X				X	X		X	X	X			X		X	X		X	X	X	X				X		X	X		X
Black walnut			X						X	X	X	X			X		X	X		X		X	X				X		X	X		X

[a] Soil Mapping Unit corresponds to the number of the soil in Table 11.

Table 14. Important features of the shrub species recommended for the Bear Creek watershed buffer strips

Species (often associated with)	Soil Requirements	Growth Rate	Tolerance to Competition	Rooting Habit	Particular Susceptibilities	Reproduction Mode	Possible Suitable Soils (%soils)[a]
Ninebark (gray dogwood)	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Wet to droughty, very poor to excessively well drained soils	Fast	Intolerant	Fibrous shallow lateral root system	Tolerates drought and flooding	Softwood cuttings	All soils (100%)
Chokecherry (oaks)	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Moist, moderately well to well drained soils (useful in erosion control)	Fast	Intermediate	Long taproot	– Intolerant of flooding – Deer browsing; black knot	– Seedling sprouts in full light – Suckers	3, 4, 7, 8, 10, 12, 15, 17, 18, 22, 24, 25, 27, 29, 30, 32 (50%)
Nannyberry (chokecherry, oaks)	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Moist to dry, moderately poor to well drained soils	Fast	Intermediate	Extensive fibrous shallow root system	Intolerant of flooding	– Cuttings – Layering	3, 4, 7, 8, 9, 10, 11, 12, 15, 17, 18, 21, 22, 24, 25, 27, 29, 30, 32 (59.5%)

Table 14. (continued)

Species (often associated with)	Soil Requirements	Growth Rate	Tolerance to Competition	Rooting Habit	Particular Susceptibilities	Reproduction Mode	Possible Suitable Soils (%soils)[a]
Silky dogwood (ninebark, willow)	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Wet to moist, very poor to well drained soils	Very fast	Very intolerant	Fibrous shallow lateral root system, stoloniferous roots	– Resistant to drought – Tolerant of flooding	– Sprouting – Layering – Suckers	2, 3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 27, 28, 29, 30, 31 (78%)
Nanking cherry	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Dry to moist, well drained soils	Slow	Intolerant	Shallow root system	Intolerant of flooding	Seeds	3, 4, 7, 8, 9, 10, 11, 12, 15, 17, 18, 21, 22, 24, 25, 27, 29, 30, 32 (59.5%)
Gray dogwood (ninebark, nannyberry, *Viburnums*)	– No specific texture requirement – Withstands acid and alkaline soils (and $CaCO_3$) – Moist to droughty, moderately poor to excessively well drained soils	Fast	Tolerant	Fibrous shallow lateral root system	– Resistant to drought – Intermediate flooding tolerance	– Sprouting – Layering – Suckers	3, 4, 7, 8, 9, 10, 11, 12, 15, 17, 18, 21, 22, 24, 25, 27, 29, 30, 32 (59.5%)

[a] The possible suitable soils are listed by their number in Table 11.
The % soils indicated is equal to the number of soils to which the species is adapted divided by the total number of soils.

layout. Information on the root system reflects both the shrub soil requirements and its capacity to anchor. Particular susceptibilities are useful to decide the location for planting. Finally, the reproduction strategy shows the ease with which the shrub will regenerate in the buffer strip. As with the tree species, these ecological characteristics have been correlated to the characteristics of the Bear Creek watershed soils to determine the possible adaptation of the shrubs to these soils. Because none of the shrubs had a specific texture requirement and were all adapted to a wide range of soil conditions, criteria of texture and pH were not limiting. The determination of the adaptation of shrubs to soils was thus solely based on depth to high water table, moisture and drainage class. Assuming they are equally important, the adaptation of a species to a soil was judged impossible when 2 criteria did not meet the shrub's requirements. Shrubs rooting systems generally are concentrated in the upper 45-50 cm, the maximum rooting depth being of 60 or 90 cm (Hortline, 1994). A soil to which a shrub is adapted needs a depth to high water table of a minimum 60 cm. As far as moisture is concerned, its distribution over the whole soil profile gives an indication of moisture holding capacity in the upper zone.

Table 14 shows that all shrubs are rather adaptable. They all have a fast growth rate, except nanking cherry. Resistance to drought and/or to periodic flooding varies among species. The degree of adaptation to soils lies between 50% and 100%. Table 15 is a recapitulation of the shrub species adapted to each soil and allows to distinguish 2 groups of species, according to their ecological range:

- species having a large ecological range (>75%): ninebark and silky dogwood;
- species having a medium ecological range (>60%): gray dogwood, nanking cherry, nannyberry and chokecherry.

Clarion, Clarion-Storden loams, Cylinder, Farrar, Hanlon-Spillville complex channeled, Hayden, Lester, Nicollet, Spillville, Storden, Storden-Hayden loams, Terril, Wadena and Waukee variant are soils to which the 6 species are adapted.

Concerning the grass component of the buffer strip, the IStART recommendation is to use a native prairie grass: switchgrass. This tall

Table 15. Recapitulation of the shrub species adapted to the Bear Creek watershed soils

Soil Mapping Unit[a] / Species	259	507	138B	638C2	135	201B	202	175	34C	253B	284	1314	95	956	168B	4	236B	55	6	274	41B	485	1585	62C3	356G	559	27B	506	108	117B	107	828B
Ninebark	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Silky dogwood		x	x	x	x	x	x			x		x	x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x	x	
Gray dogwood			x	x			x	x	x	x	x	x			x		x	x			x	x		x	x		x		x	x		x
Nanking cherry			x	x			x	x	x	x	x	x			x		x	x			x	x		x	x		x		x	x		x
Nannyberry			x	x			x	x	x	x	x	x			x		x	x			x	x		x	x		x		x	x		x
Chokecherry			x	x			x	x	x	x	x	x			x		x	x				x		x	x		x		x	x		x

[a] Soil Mapping Unit corresponds to the number of the soil in Table 11.

perennial grass has roots so vigorous that they can extend up to 3 m or more into the soil (Best, 1971; Boon and Groe, 1990). Results of the experimental BCBS at the Risdal farm have even shown that it produces 1700 kg/ha of root biomass in the first 43 cm of soil (IStART, 1993). Switchgrass is a stiff stemmed grass that requires moisture and is usually found on lowland, wet to mesic prairies, streambanks and open woodlands. It is suitable to most of the Bear Creek watershed soils.

The IStART choice also includes the possibility of mixing switchgrass with other native permanent grasses such as yellow Indian grass and big bluestem. This seems to be a good idea since diversity is present in natural conditions. Yellow Indian grass is good to mix with switchgrass because it does not usually grow in pure stands (Boon and Goe, 1990). The root system is not as developed as swithgrass. This erect perennial prairie grass is found on upland mesic to dry prairies and on streambanks (Best, 1971; Boon and Groe, 1990). Although it can survive on drier sites, it prefers moist soils. It is suitable to most Bear Creek watershed soils. As far as big bluestem is concerned, it is a tall perennial grass which grows in close association with these 2 previous species, making it an excellent choice. Its roots saturate the top 60 cm of soil and can reach depths of 3.5 m. It is usually found on lowland, wet to mesic prairies and open woodlands. This erect prairie grass also requires moisture. It is adapted to most of the Bear Creek watershed soils too.

One important point, according to the IStART's recommendation, is that the mixture of switchgrass with yellow Indian grass and big bluestem can only be used if switchgrass remains dominant. One reason is the switchgrass capacity of root development and streambank stabilization. It is also a stiff non-bunch grass which intercepts and slows overland flow better than other species. Some native forbs could also be added to the grass mixture to enhance vegetation diversity and benefit wildlife.

Figure 17 is a diagram representing the construction of a buffer strip on any site of the riparian zone in the Bear Creek watershed. In this diagram, the location on the north side or the south side of the waterway was used to differentiate the species composition. Cases b and c (Figure 10) correspond to either a medium or a high erosion potential. Willows need to be planted in the

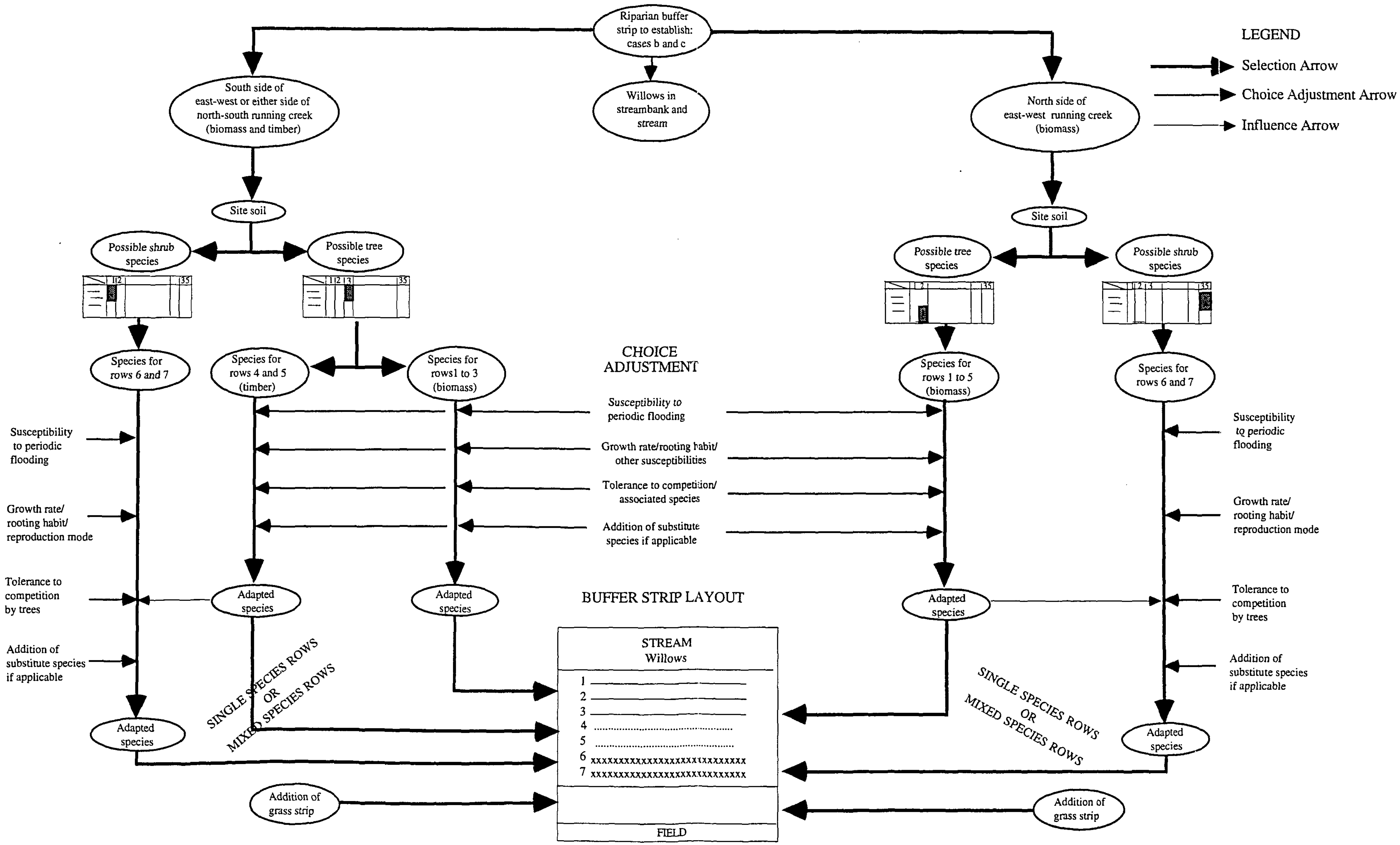


Figure 17. Riparian buffer strip vegetation construction diagram for the Bear Creek watershed

streambank and in the stream in situations where erosion potential is either medium or high.

One has to refer to Tables 13 and 15 that show species adapted to specific soils in order to determine which ones can be used on the BCBS. Because of shading, the north side buffer of the creek will only be comprised of biomass trees, shrubs and grass, whereas a south side buffer on an east-west running stream or either side of a north-south running stream can include biomass and timber trees, shrubs and grass.

The next step in selecting the species requires a review of the species ecological characteristics found in Tables 12 and 14. Final adjustments in tree species combinations should be made with this review. Shrub selection follows a similar sequence.

The last step in the selection of the riparian buffer vegetative cover consists, in all cases, in the addition of the strip of grass at the interface with the crop field.

For the tree and shrub rows (rows 1 to 7 on Figure 17), it may be interesting to note that it is possible to establish either pure species rows or mixed species rows. With a design comprising only pure species rows, there will be one row of one species then another row of another single species and so on. With a mixed species row design, it would be possible to alternate two or more species on the basis of every other tree (shrub) or every two or three trees (shrubs). Although within row species mixing can intensify competition and complicate harvesting (species of different sizes), the major advantage is better protection of streambank stability in the event of a devastating disease or pest infestation of one species. This would avoid the loss of an entire single species row. Another advantage is the protection against animals such as beavers, rabbits or deer that can cause an entire single species row to die. Within row mixing also simulates a more or less natural looking riparian plant community.

To illustrate how the buffer strip construction diagram (Figure 17) works, we will take the example of a Spillville-Coland complex channeled soil site located on the east side of a north-south running creek reach, south of Roland. This site is identified on Figure 8 as vulnerable for NPS pollution with a medium potential. According to Figure 10, we are in a b case for the establishment of a BCBS. This BCBS will comprise biomass and timber trees as well as shrubs and grass (Figure 17).

Step 1: The mapping unit of Spillville-Coland complex is 1585 in Table 11.

Step 2: Tables 13 and 15 tell which species are suitable for planting on the site:

- *Tree species*:

* biomass: silver maple, willow and cottonwood;

* timber: bur oak, hackberry, green ash, northern red oak and black walnut;

- *Shrub species*:

ninebark and silky dogwood.

Step 3: The adjustment of the choice is then performed with Tables 12 and 14.

Trees:

. The site is subject to events that can occur more than once in 2 years (Figure 6). These events can damage mainly the timber species at a young age. Bur oak and northern red oak would be most sensitive.

. Vigor, assessed with the growth rate, the rooting habit and the particular susceptibilities, does not eliminate any species, though it indicates cottonwood hybrid, green ash and black walnut are more fragile (frequent damage by animals, insects or diseases).

. Tolerance to competition and the associated species, together with the growth rate, help to guide the way to associate the trees. Bur oak, northern red oak and hackberry grow slowly, which allows them to associate with each other. Since they are all intermediate in tolerance, any combination will be possible. Green ash and black walnut have a fast growth rate and are intolerant. It will therefore be better to associate them with a slow growing species having a good or medium tolerance, which is the case of the other 3 species. Several associations with the suitable timber species will thus be feasible. Among the 3 biomass species, the choice of the layout should probably take into account the competition that will occur between willow and the poplar hybrid. If the objective of the landowner is to maximize biomass

production, maybe only one of these 2 species should be selected to plant with silver maple.
. Substitute species are not needed.

Shrubs:
. The criteria of susceptibility to flooding is not discriminating.
. Vigor, assessed with the growth rate, the rooting habit and the reproduction mode, does not eliminate any species either. They will be able to expand on the ground and cover it well.
. As far as tolerance to competition is concerned, ninebark is intolerant to shade and silky dogwood very intolerant. Their development could therefore be somewhat hindered. In addition, their root system could interfere with the one of the trees.
. No substitute species are needed.

Step 4: The strip of grass is added.

Substitute tree and shrub species mentioned in the buffer strip construction diagram (Figure 17) are intended to substitute for species selected at the beginning of the decision model but eliminated afterwards due to some of their ecological characteristics. These substitute species have to be chosen carefully. They should be native to central Iowa and present ecological features corresponding to the characteristics of the soils that caused the elimination of the original species.

Among the tree species, soil characteristics causing adaptation problems are mostly a poor drainage associated with a shallow depth to high water table. Similar characteristics are responsible for a lack of adaptation by shrubs. Substitute tree and shrub species must therefore be able to withstand such conditions. Although the list is not exhaustive, poplar hybrids capable of thriving on very poorly drained soils could be suggested. Eastern wahoo (*Euonymus atropurpureus* Jacq.), elderberry (*Sambuscus canadensis* L.) and willow managed as coppice could be substitute shrubs.

Other species that might be considered if the original ones are unavailable include box elder (*Acer negundo* L.), sugar maple (*Acer saccharum* Marsh.) , black maple (*Acer nigrum* Michx), shagbark hickory (*Carya ovata* (Mill.) K.

Koch) and a shrub like serviceberry (*Amelanchier arborea* (Michx.) Fern.) would be examples insofar as their ecological characteristics match the Bear Creek watershed soils'.

Site preparation and planting

In addition to selecting species for a BCBS, it is important to give some general guidelines about site preparation and planting.

Reduction of weed competition is considered critical for the establishment of newly planted seedlings. It allows them to utilize the nutrients and moisture that would have been used by the weeds (Lantagne et al., 1986). In the BCBS, there is a double objective. Successful establishment of seedlings is one. The other is the maintenance of a cover of grass on the ground as extensive as possible to prevent erosion and maximize the sediment filtering function. Since weeds compete with trees in the early years of development, trade-offs are involved. Strips of pasture grass into which seedlings are planted can be prepared either by tillage or by herbicide application. Tillage is a method that will optimize soil moisture, release nutrients and improve soil physical properties (Lantagne and Burger, 1982) if the land was previously cultivated or very heavily grazed. Herbicides have been proven to be very effective in controlling weed competition and enhancing seedling growth (Shoenholtz and Buie, 1987; South and Barnett, 1986). Site preparation using a contact herbicide such as glyphosate (Roundup) is appropriate here to eliminate just the amount of weeds needed. Only a contact herbicide should be used because of the potential leaching problems of other herbicides.

An alternative to control weeds would be to establish cover crops. They provide good competition control and stimulate seedling growth (Schlesinger and Van Sambeek, 1986). However, in the BCBS situation, leguminous cover crops would not be used because they enrich soil in nitrogen. Perennial rye (*Lolium perenne* L.) and timothy grass (*Phleum pratense* L.) would thus be an appropriate mixture.

Hardwood species are generally successfully established in the Midwest when planted as one- or two-year old seedlings or for some species such as cottonwood as unrooted stem cuttings (Barrett, 1980). This is the kind of stock to use for the BCBS. Streambank stabilization by willows requires the use of cuttings. Planting should occur between April 1 and May 15, although fall planting is possible (Thompson, 1992). Depending on the site, planting either by hand or by machine can be efficient (Lantz et al., 1989). Open tracts are more easily planted by machine, whereas irregularly shaped tracts or wet areas are more easily hand planted. Guarding against improper planting practices is a key to establishment success (Lantz et al., 1989). Use of quality stock with a good root to shoot ratio and proper root morphology is also important (Schultz and Thompson, 1991, 1992).

IStART's recommendations for spacing are 1.2 m within row for the trees and 1 m within row for the shrubs (IStART, 1993). There should be 1.8 m between the rows of trees and shrubs. To facilitate maintenance, this spacing could be increased to 2.4 m. The number of tree rows would then be reduced to 4, which would decrease establishment cost. Landowner's objectives will help determine this spacing. Concerning the grass, a dense cover should be obtained with a seeding rate of about $1g/m^2$. Seeds can be sown by hand or by mechanical drill and the best time for sowing is April (Hewlett et al., 1987; Thompson, 1992).

Maintenance

Since a buffer strip is a nutrient sink, its continued efficiency in reducing NPS pollution depends on plant vigorous growth.

Performing a minimum of weed control after establishment may be necessary, as it may adversely influence seedling growth (case of black walnut and cottonwood). Controlling competition should be done during the first 3 to 5 years after planting until seedlings are tall or dense enough to suppress competition (Thompson, 1992). A mechanical control needs to be repeated frequently. A herbicide treatment is a more effective method, with longer lasting effects. A pre-emergent contact herbicide could then be applied early spring. However, because of potential pollution problems, this practice should be used with caution and only if really needed. If cover crops are established, they provide an efficient means of weed control.

The strip of biomass trees will be left undisturbed to provide a maximum of water quality protection and streambank stabilization maintenance (IStART, 1993). However, removal of the stems of these species will be planned on an 8 to 12 year rotation basis to ensure the removal of the sequestered pollutants (Chapter 2). Since these species have the ability to regenerate from stump sprouts, the root systems will remain intact, which will not affect soil stability. They will also regrow very fast. The collected wood will represent an income for the landowner and can be used as firewood (the stems will have a small diameter). It needs to be noted that every 5 rotations (approximately every 40 years), new plantings will need to be done.

The strip of timber trees will be managed to produce high quality wood that represents a potentially important future income for the landowner. To achieve this goal, trees need to be pruned at a young age. The stand also should be thinned to favor timber production. After removal of the mature trees on approximately a 50 year rotation, which also ensures the removal of sequestered nutrients, immediate replanting will need to be done, so there is continued sequestering of pollutants.

Concerning the maintenance of the strip of shrubs, one has to remember that newly planted shrubs lack deeply penetrating roots and are more vulnerable to drought and wind (Taylor, 1987). It is thus important that they develop a vigorous root system. Pruning shrubs helps them put out vigorous new growth (Zucker, 1966). It could thus be advised to prune about one third of the top growth approximately 3 years after planting. This stimulates growth of the root system, which benefits the NPS pollution reduction function of the buffer. Above ground growth is also favored by such pruning. After that pruning, others should occur every 4 years so that shrubs do not impede each other's growth.

As far as the grass strip is concerned, the recommendation is to maintain a vigorous growth so that sediment filtering, nutrient uptake, the interception of the concentrated surface flow and its conversion to a uniform sheet flow can be continuously well performed. During the first 2 growing seasons, weed control can be beneficial to speed up establishment since warm-season perennial grasses are vulnerable to weed competition (annual species in particular)

(Hewlett et al., 1987; McKenna et al., 1991; Thompson, 1992). Periodically harvesting the grass (at least once a year) is necessary (Agriculture Canada, 1992; Soil Conservation Service, 1993; Welsch, 1991). Not only does this maintain a dense grass cover and promote vigorous growth, but it also removes sequestered nutrients. Cutting should occur during the growing season and grass should not be cut shorter than 50 mm (Hewlett et al., 1987).

Besides these guidelines, damage to BCBS by various animals cannot be overlooked. Deer browsing and rabbit damage are examples. The population of beavers should particularly be of concern. Damage to trees and the construction of dams that disrupt water levels (making riparian areas more prone to flooding) can be serious problems. Finally, it may be useful to make a note that the application of some pesticides like atrazine on the corn or soybean field next to the buffer strip may have adverse unwanted effects. Switchgrass and cottonwood are particularly susceptible (Bercovici F., 1991; Burns and Honkala, 1990; McKenna et al., 1991). On previously cropped fields, grass seeds can be damaged by herbicide carryover (Thompson, 1992).

In conclusion, it had appeared useful to try to carry on the work done to date by IStART for the establishment of BCBS. A guide for the determination of the vegetative cover to establish on areas identified as needing a buffer zone was therefore developed. Ecological features of the species selected by IStART were combined with the characteristics of the watershed soils. Plant adaptation to soils was then assessed and a general BCBS construction model generated. The decision diagram included an adjustment of the choice of species because it was deemed important to insure that the vegetation cover is extremely healthy and vigorous. In addition, choosing timber species that will do well is necessary so the landowner - as with the rapid growth of the biomass species - will not see a failure in the promising benefits of his riparian buffer strip. Guidelines for the establishment and maintenance of the BCBS were also given, since continued efficiency of buffer zones is critical in mitigating NPS pollution in the waterhed. Further improvement of this guide to vegetation selection is encouraged. In particular, field forms could be developed to facilitate implementation.

CHAPTER 7. CONCLUSIONS

Water resource impacts are among the most important environmental effects of agriculture. Throughout the United States, agricultural activities contribute significantly to NPS pollution of surface water and groundwater through soil erosion and fertilizer and pesticide application. The land immediately adjacent to streams is the key to protecting water quality. Since this land can be managed to protect riparian values, a buffer strip zone can be designed to preserve the water resources of the Bear Creek watershed, in central Iowa. Such vegetated riparian zones have been shown to be effective in reducing NPS pollution of the water by trapping sediment and serving as nutrient sinks for agricultural chemicals. Vegetated riparian corridors also improve wildlife habitat and are an aesthetic addition in the landscape. This addition was present under natural conditions before economic pressures and deforestation suppressed streambanks' vegetation.

Reviewing literature showed a lack of information concerning the criteria to use to determine riparian areas vulnerable for NPS pollution. In the Bear Creek study, soil erosion K factor, slope, flooding frequency and soil drainage class were selected as having the most critical effect on water quality degradation. A watershed-scale analysis of each was undertaken. It revealed that more than half the area has a medium or high potential for erosion, with 27 km of the Bear Creek length presenting a medium erosion hazard and 6.8 km a high erosion hazard. Occasional and frequent flooding frequencies were identified in the riparian zone, with 19.9 km of the stream lying along occasionally flooded soils and 18.5 km along frequently fooded soils. Half the watershed soils have a somewhat poor to very poor drainage. Poorly drained areas are dominant (35.5 % of the watershed area) and located both in the upland and along the stream. The combination of these three factors on a single map clearly indicated that a large portion of the drainage basin is vulnerable to NPS pollution, 91% of the area being in medium or high vulnerability. Streamside areas were found to be particularly sensitive, with

77.5 % of the 20 m wide riparian zone identified as medium or high risk. Sites identified as vulnerable (medium or high vulnerability potential) could benefit from modified management practices. The recommendation is to establish vegetated riparian buffer strips. This recommendation can be extended beyond the riparian zone, with adjustments to specific situations (ie: animal feedlots).

There was little data on suitable widths for buffer strips. Since each watershed is distinct, there probably would be a need for flexibility in the width requirement. In the Bear Creek case, the recommendation is to establish 20 m buffer strips, though it is clear this may not be exact and not general for all agricultural watershed situations. The 20 m width being used in this watershed was selected because of cost-share program requirements. The application of guidelines used for riparian forest buffers in the eastern United States has however pointed out the need for an increase of the width in riparian zones with a land capability class of III.

Riparian vegetation plays a key role in the quality of water. Comparison of land use along the riparian zone in the watershed showed that current practices in the vulnerable areas are mostly row crops. Such annual cover does little to prevent surface runoff and chemical delivery to the stream. The recommendation is that farmers cultivate up to 20 m from the stream and modify land practices on the remaining strip of land. Although the importance of riparian ecosystems is well recognized, guidelines for the vegetation cover composition of a filter strip and its management are presently limited. Most research has been conducted on existing natural forested buffer strips. Little work has been done on reconstructing perennial plant buffer strips where none existed because of agricultural management.

The Bear Creek buffer strip project represents a unique multispecies design, capable of providing multiple environmental and economic benefits. Its combination of trees, shrubs and grass has a high potential for filtering surface runoff and water flow within the root zone. A guide was developed to help define the vegetation composition of any BCBS based on previous recommendations for the choice of riparian plant species. Ecological features of the species were combined with the characteristics of the watershed soils. Plant adaptation to soils was then assessed and a general BCBS vegetation decision model developed. Guidelines about site preparation, planting and maintenance also were given since continued efficiency of buffer zones is critical in mitigating NPS pollution in the watershed. One important factor that can adversly affect this efficiency is the presence of drainage tiles. It is possible that many concentrated upland pollutants will by-pass the vegetative filters. This would render them useless.

The research project will certainly improve current knowledge on the management of riparian zones and the restoration of watershed water resources. More work needs to be done to assess the exact economic impact on farmers of the amount of land that would have to be devoted to buffer strips. Lastly, we need to keep in mind that, no matter what kinds of efforts we put in riparian area restoration, there are no perfect solutions to return a riparian zone to its pre-disturbance condition. There is an urgent need to overcome our knowledge limitations and to improve our management techniques as " riparian systems disappear because the values associated with alternative uses of the land are greater than the preservation, maintenance or enhancement of this ecosystem" (Schmidt, 1991).

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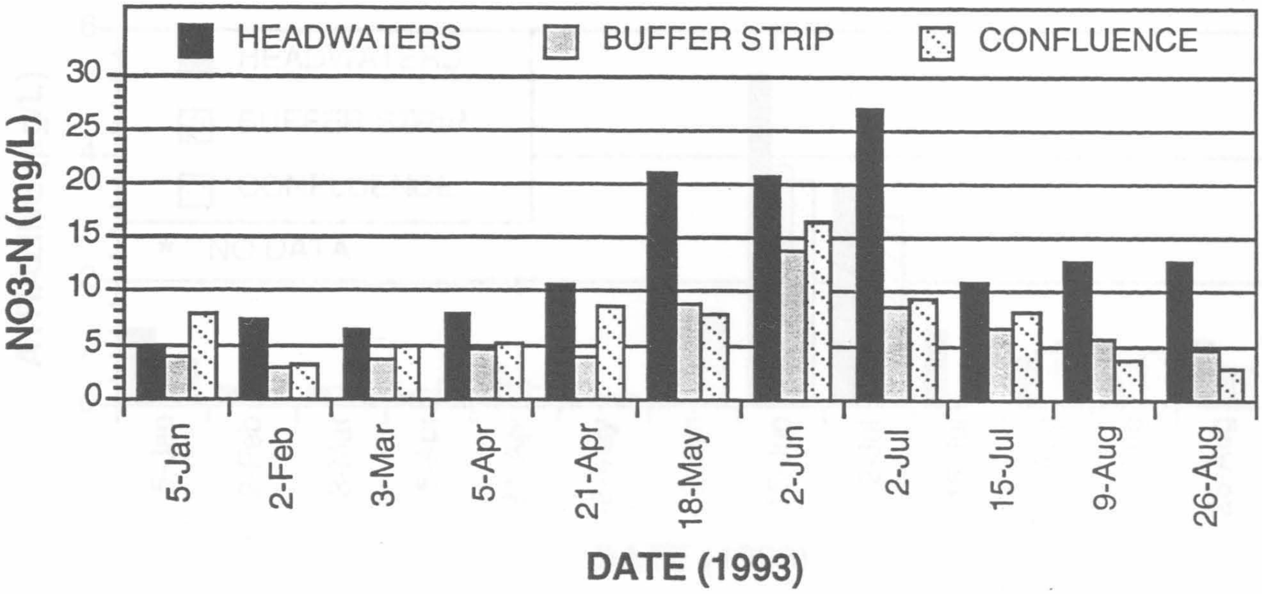
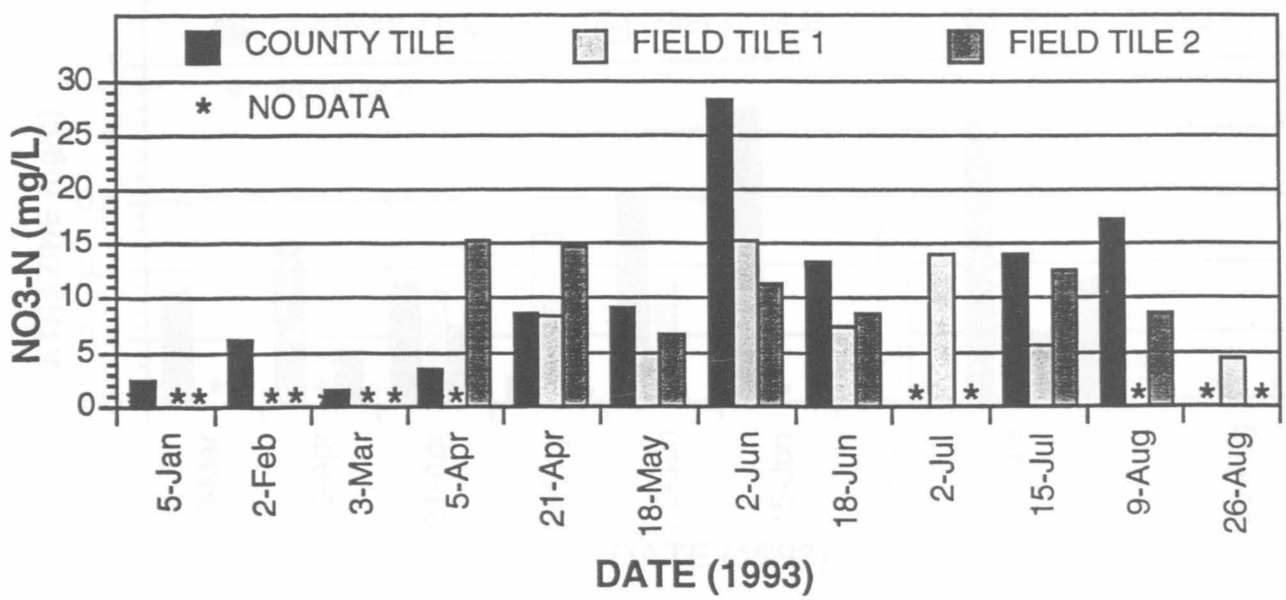
APPENDIX A. NITRATE POLLUTION IN BEAR CREEK

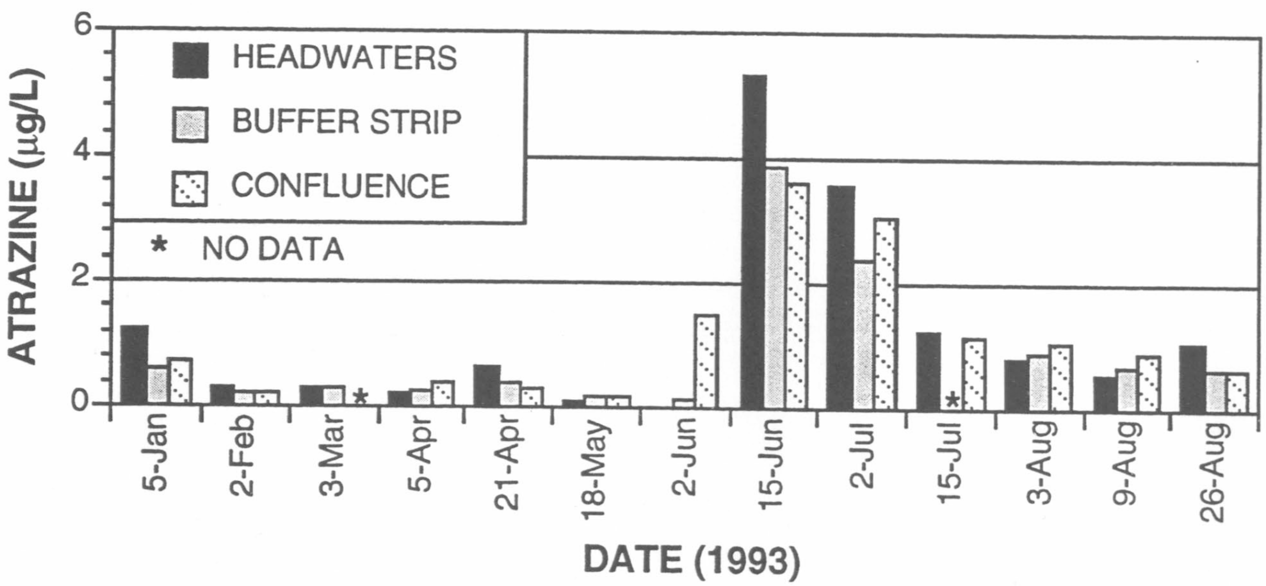


1993 creek water nitrate-nitrogen concentrations at a headwaters station, at the BCBS experimental site and at the confluence with Skunk River (IStART, 1993)

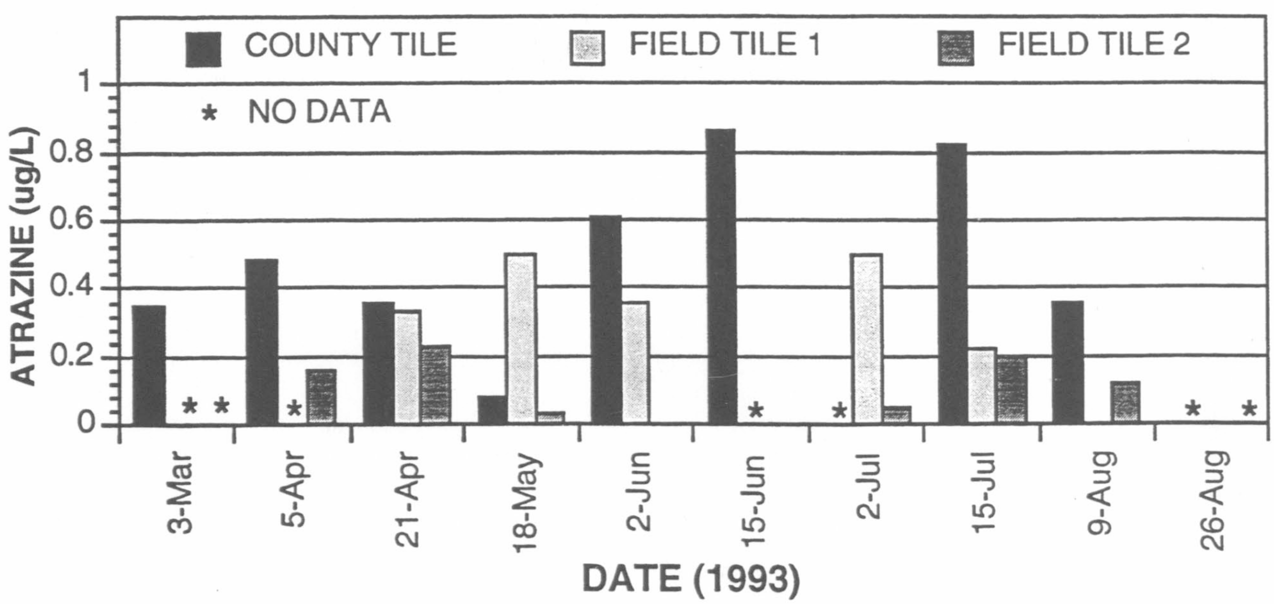


1993 tile water nitrate-nitrogen concentrations in different tiles (IStART, 1993)

APPENDIX B. PESTICIDE POLLUTION IN BEAR CREEK



1993 creek water atrazine concentrations at a headwaters station, at the BCBS experimental site and at the confluence with Skunk River (IStART, 1993)



1993 tile water atrazine concentrations in different tiles (IStART, 1993)